

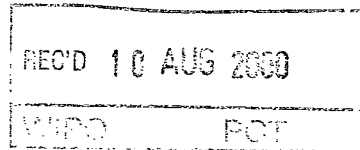


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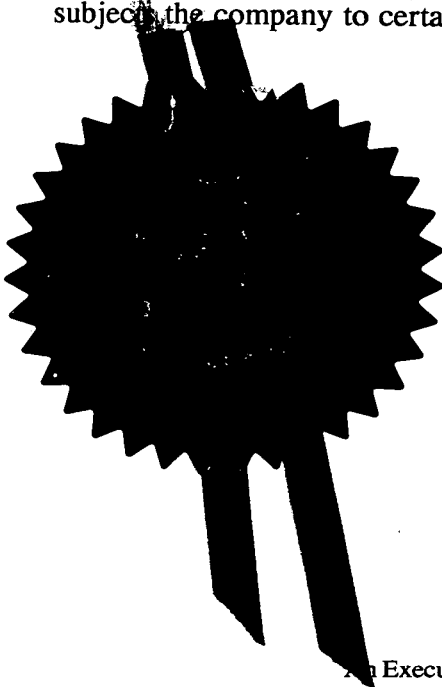
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Patents ADP number (if you know it)	7466324-001		
If the applicant is a corporate body, give the country/state of its incorporation	GB		
4. Title of the invention	POLYKETIDES AND THEIR SYNTHESIS		
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POLYKETIDES AND THEIR SYNTHESIS

The present invention relates to processes and materials (including enzyme systems, nucleic acids, vectors and cultures) for preparing polyketides, particularly polyethers but including polyenes, macrolides and other polyketides by recombinant synthesis, and to the polyketides so produced, particularly novel polyketides. (N.B the term "polyketide" is being used in its conventional sense to include structures notionally derived by the reduction and/or other processing or modification of one or more Ketide units). Furthermore the invention provides the entire nucleic acid sequence of the biosynthetic gene cluster that governs the production of the ionophoric antibiotic polyether polyketide monensin in *Streptomyces cinnamonensis*, and the use of all or part of the cloned DNA first, in the specific detection of other polyether biosynthetic gene clusters; secondly in the engineering of mutant strains of *S. cinnamonensis* and of other actinomycetes which are suitable host strains for the high level production of novel recombinant polyketides; and thirdly in the provision of recombinant biosynthetic genes which lead to such novel polyketide products.

Polyketides are a large and structurally diverse class of natural products that includes many compounds possessing antibiotic or other pharmacological properties, such as erythromycin, tetracyclines, rapamycin, avermectin, monensin, epothilones and FK506. In particular, polyketides are abundantly produced by

Streptomyces and related actinomycete bacteria. They are synthesised by the repeated stepwise condensation of acylthioesters in a manner analogous to that of fatty acid biosynthesis. The greater structural diversity found among natural polyketides arises from the selection of (usually) acetate or propionate as "starter" or "extender" units; and from the differing degree of processing of the β -keto group observed after each condensation. Examples of processing steps include reduction to β -hydroxyacyl-, reduction followed by dehydration to 2-enoyl-, and complete reduction to the saturated acylthioester. The stereochemical outcome of these processing steps is also specified for each cycle of chain extension. In addition, the biosynthetic pathways to many polyketides involve additional enzyme-catalysed modifications which may include: methylation by O- and C-methyltransferases, hydroxylation by cytochrome P450 enzymes, other oxidation or reduction processes, and the biosynthesis and attachment of novel sugars and/or deoxy sugars.

The biosynthesis of polyketides is initiated by a group of chain-forming enzymes known as polyketide synthases. Two classes of polyketide synthase (PKS) have been described in actinomycetes. One class, named Type I PKSs, represented by the PKSs for the macrolides erythromycin, oleandomycin, avermectin and rapamycin, consists of a different set or "module" of enzymes for each cycle of polyketide chain extension. (For examples see Cortés, J. *et al.* *Nature* (1990) 348:176-178; Donadio, S. *et al.* *Science* (1991) 252:675-679; Swan, D.G. *et al.*

Mol. Gen. Genet. (1994) 242:358-362; MacNeil, D.J. et al. Gene (1992) 115:119-125; Schwecke, T. et al. Proc. Natl. Acad. Sci. USA (1995) 92:7839-7843.)

The term "extension module" as used herein refers to the set of contiguous domains, from a β -ketoacyl-ACP synthase ("KS") domain to the next acyl carrier protein ("ACP") domain, which accomplishes one cycle of polyketide chain extension. The term "loading module" is used to refer to any group of contiguous domains which accomplishes the loading of the starter unit onto the PKS and thus renders it available to the KS domain of the first extension module. The length of polyketide formed has been altered, in the case of erythromycin biosynthesis, by specific relocation using genetic engineering of the enzymatic domain of the erythromycin-producing PKS that contains the chain releasing thioesterase/cyclase activity (Cortés J. et al. Science (1995) 268:1487-1489; Kao, C.M. et al. J. Am. Chem. Soc. (1995) 117:9105-9106).

In-frame deletion of the DNA encoding part of the ketoreductase domain in module 5 of the erythromycin-producing PKS (also known as 6-deoxyerythronolide B synthase, DEBS) has been shown to lead to the formation of erythromycin analogues 5,6-dideoxy-3- α -mycarosyl-5-oxoerythronolide B, 5,6-dideoxy-5-oxoerythronolide B and 5,6-dideoxy,6- β -epoxy-5-oxoerythronolide B (Donadio, S. et al. Science (1991) 252:675-679). Likewise, alteration of active site residues in the enoylreductase domain of module 4 in DEBS, by genetic engineering of the corresponding PKS-encoding DNA and its introduction into

Saccharopolyspora erythraea, led to the production of 6,7-anhydroerythromycin C (Donadio, S. et al. Proc. Natl. Acad. Sci. USA (1993) 90:7119-7123).

International Patent Application number WO 93/13663 describes additional types of genetic manipulation of the DEBS genes that are capable of producing altered polyketides. However many such attempts are reported to have been unproductive (Hutchinson, C.R. and Fujii, I. Annu. Rev. Microbiol. (1995) 49:201-238, at p. 231). The complete DNA sequence of the genes from *Streptomyces hygroscopicus* that encode the modular Type I PKS governing the biosynthesis of the macrocyclic immunosuppressant polyketide rapamycin has been disclosed (Schwecke, T. et al. (1995) Proc. Natl. Acad. Sci. USA 92:7839-7843). The DNA sequence is deposited in the EMBL/Genbank Database under the accession number X86780.

WO 98/01546 discloses that a PKS gene assembly (particularly of Type I) encodes a loading module which is followed by at least one extension module. The first open reading frame encodes the first multi-enzyme or cassette (DEBS1) which consists of three modules: the loading module (ery-load) and two extension modules (modules 1 and 2). The loading module comprises an acyltransferase and an acyl carrier protein. This may be contrasted with Figure 1 of WO 93/13663 (referred to above). This shows ORF1 as only two modules, the first of which is in fact both the loading module and the first extension module.

WO 98/01546 describes in general terms the production of a hybrid PKS gene assembly comprising a

loading module and at least one extension module. It also describes (see also Marsden, A.F.A. et al. Science (1998) 279:199-202) construction of a hybrid PKS gene assembly by grafting the wide-specificity loading module for the avermectin-producing polyketide synthase onto the first multi-enzyme component (DEBS1) for the erythromycin PKS in place of the normal loading module. Certain novel polyketides can be prepared using the hybrid PKS gene assembly, as described for example in WO 98/01571.

WO 98/01546 further describes the construction of a hybrid PKS gene assembly by grafting the loading module for the rapamycin-producing polyketide synthase onto the first multi-enzyme component (DEBS1) for the erythromycin PKS in place of the normal loading module. The loading module of the rapamycin PKS differs from the loading modules of DEBS and the avermectin PKS in that it comprises a CoA ligase domain, an enoylreductase ("ER") domain and an ACP, so that suitable organic acids including the natural starter unit 3,4-dihydroxycyclohexane carboxylic acid may be activated *in situ* on the PKS loading domain and, with or without reduction by the ER domain, transferred to the ACP for intramolecular loading of the KS of extension module 1 (Schwecke, T. et al. Proc. Natl. Acad. Sci. USA (1995) 92:7839-7843). WO 98/51695 and WO 98/49315 describe additional types of genetic manipulation of the DEBS genes that are capable of producing altered polyketides.

The second class of PKS, named Type II PKSs, is represented by the synthases for aromatic compounds. Type II PKSs contain only a single set of enzymatic activities

for chain extension and these are re-used as appropriate in successive cycles (Bibb, M.J. et al. EMBO J. (1989) 8:2727-2736; Sherman, D.H. et al. EMBO J. (1989) 8:2717-2725; Fernandez-Moreno, M.A. et al. J. Biol. Chem. (1992) 267:19278-19290). The "extender" units for the Type II PKSs are usually acetate units, and the presence of specific cyclases dictates the preferred pathway for cyclisation of the completed chain into an aromatic product (Hutchinson, C.R. and Fujii, I. Ann. Rev. Microbiol. (1995) 49:201-238). Hybrid polyketides have been obtained by the introduction of cloned Type II PKS gene-containing DNA into another strain containing a different Type II PKS gene cluster, for example by introduction of DNA derived from the gene cluster for actinorhodin, a blue-pigmented polyketide from *Streptomyces coelicolor*, into an anthraquinone polyketide-producing strain of *Streptomyces galileus* (Bartel, P.L. et al. J. Bacteriol. (1990) 172:4816-4826).

The minimal number of domains required for polyketide chain extension on a Type II PKS when expressed in a *Streptomyces coelicolor* host cell (the "minimal PKS") has been defined for example in WO 95/08548 as containing the following three polypeptides which are products of the *actI* genes: firstly KS; secondly a polypeptide termed the CLF with end-to-end amino acid sequence similarity to the KS but in which the essential active site residue of the KS, namely a cysteine residue, is substituted either by a glutamine residue or, in the case of the PKS for a spore pigment such as the *whiE* gene product (Davis, N.K. and Chater,

K.F. Mol. Microbiol. (1990) 4:1679-1691) by a glutamic acid residue; and finally an ACP. The CLF has been stated (for example in WO 95/08548) to be a factor that determines the chain length of the polyketide chain that is produced by the minimal PKS. However it has been found (Shen, B. et al. J. Am. Chem. Soc. (1995) 117:6811-6821) that when the CLF for the octaketide actinorhodin is used to replace the CLF for the decaketide tetracenomycin in host cells of *Streptomyces glaucescens*, the polyketide product is not found to be altered from a decaketide to an octaketide, so the exact role of the CLF remains unclear. An alternative nomenclature has been proposed in which KS is designated KS α and CLF is designated KS β , to reflect this lack of knowledge (Meurer, G. et al. Chemistry & Biology (1997) 4:433-443). The mechanism by which acetate starter units and acetate extender units are loaded onto the Type II PKS is not known, but it is speculated that the malonyl-CoA: ACP acyltransferase of the fatty acid synthase of the host cell can fulfil the same function for the Type II PKS (Revill, W.P. et al. J. Bacteriol. (1995) 177:3946-3952).

WO 95/08548 describes the replacement of actinorhodin PKS genes by heterologous DNA from other Type II PKS gene clusters, to obtain hybrid polyketides. It also describes the construction of a strain of *Streptomyces coelicolor* which substantially lacks the native gene cluster for actinorhodin, and the use in that strain of a plasmid vector pRM5 derived from the low-copy number vector SCP2* isolated from *Streptomyces coelicolor* (Bibb, M.J. and Hopwood, D.A. J. Gen. Microbiol. (1981)

126:427-442) and in which heterologous PKS-encoding DNA may be expressed under the control of the divergent *actI/actIII* promoter region of the actinorhodin gene cluster (Fernandez-Moreno, M.A. et al. J. Biol. Chem. (1992) 267:19278-19290). The plasmid pRM5 also contains DNA from the actinorhodin biosynthetic gene cluster encoding the gene for a specific activator protein, ActII-orf4. The ActII-orf4 protein is required for transcription of the genes placed under the control of the *actI/actIII* bidirectional promoter and activates gene expression during the transition from growth to stationary phase in the vegetative mycelium (Hallam, S.E. et al. Gene (1988) 74:305-320).

Type II clusters in *Streptomyces* are known to be activated by pathway-specific activator genes (Narva, K.E. and Feitelson, J.S. J. Bacteriol. (1990) 172:326-333; Stutzman-Engwall, K.J. et al. J. Bacteriol. (1992) 174:144-154; Fernandez-Moreno, M.A. et al. Cell (1991) 66:769-780; Takano, E. et al. Mol. Microbiol. (1992) 6:2797-2804; Gramajo, H.C. et al. Mol. Microbiol. (1993) 7:837-845). The DnrI gene product complements a mutation in the *actII-orf4* gene of *S. coelicolor*, implying that DnrI and ActII-orf4 proteins act on similar targets. A gene (*srmR*) has been described (EP 0 524 832 A2) that is located near the Type I PKS gene cluster for the macrolide polyketide spiramycin. This gene specifically activates the production of the macrolide antibiotic spiramycin, but no other examples have been found of such a gene. Also, no homologues of the ActII-orf4/DnrI/RedD

family of activators have been described that act on Type I PKS genes. WO 98/01546 describes the use of the ActII-orf4 family of activators in conjunction with their cognate promoters (e.g actII-orf4 with the *actI* promoter) in a heterologous actinomycete to obtain high level expression of recombinant Type I polyketide synthase genes.

Although large numbers of therapeutically important polyketides have been identified, there remains a need to obtain novel polyketides that have enhanced properties or possess completely novel bioactivity. The complex polyketides produced by Type I PKSs are particularly valuable, in that they include compounds with known utility as anthelmintics, insecticides, immunosuppressants, antifungal agents or antibacterial agents. Because of their structural complexity, such novel polyketides are not readily obtainable by total chemical synthesis, nor by chemical modifications of known polyketides.

There is also a need to develop reliable and specific ways of deploying individual genes and portions of genes in practice so that all, or a large fraction, of hybrid PKS genes that are constructed, are viable and produce the desired polyketide product. This includes the development of advantageous host strains for expression of such genes. For example many polyketides are rendered bioactive by the action of further enzymes other than the polyketide synthase, and host strains that contain and are able to express the genes for such enzymes are particularly convenient for the efficient synthesis of

the bioactive material. In those cases where the construction of a known or a novel polyketide requires specialised precursors, host strains containing and able to express the genes for key enzymes that enhance the production of such specialised precursors are equally valuable and desirable. There is also a need to develop rational methods of increasing the expression level of all the genes required for production of a specific polyketide. Clearly also a host cell which is advantageous for the above reasons, and/or because of other favourable characteristics including but not limited to its speed of growth, excellent handling characteristics in fermentation, and ease of transformation with DNA by various techniques, can be made even more favourable by the cloning into that cell of such auxiliary genes for polyketide modification, or gene activation, or post-translational modification, or precursor supply.

The DNA sequences have been disclosed for several Type I PKS gene clusters that govern the production of 16-membered macrolide polyketides, including the tylosin PKS from *Streptomyces fradiae* (application EP 0 791 655 A2), the niddamycin PKS from *Streptomyces caelestis* (Kavakas, S.J. et al. J. Bacteriol. (1997) 179:7515-7522) and the spiramycin PKS from *Streptomyces ambofaciens* (application EP 0791 655 A2). DNA sequences have also been disclosed for Type I PKS gene clusters that govern the production of further complex polyketides, for example rifamycin from *Amicolatopsis mediterranei* (WO

98/07868), and soraphen from *Sorangium cellulosum* (US 5716849), but so far no DNA sequence has been disclosed for one of the most widespread and important classes of complex polyketides, the polyethers.

5 Polyethers form an important group of complex polyketide antibiotics (Westley, J.W. in "Antibiotics IV. Biosynthesis" (Corcoran, J.W. Ed.), Springer-Verlag, New York (1981) p. 41-73). They are polyoxygenated carboxylic acids which act as selective ionophores transporting
10 cations across the cell membrane of target cells and thereby causing depolarisation and cell death. Certain polyethers including monensin, lasalocid and tetronasin are in widespread use in animal husbandry as coccidiostats (principally targetted against *Eimeria*
15 spp.) and as growth promoters. Polyethers have also been reported to be active *in vitro* and *in vivo* against the malarial parasite *Plasmodium falciparum* (Gumila, C. et al. Antimicrobial Agents and Chemotherapy (1997) 41: 523-529).

20 Polyethers contain multiple asymmetric centres and are characterised by the presence of tetrahydrofuran and tetrahydropyran rings, producing a characteristic shape which is non-polar on its outer surface and therefore well adapted for transport of material across bacterial
25 membranes; and provides on its inner surface polar coordinating ligands for a centrally-bound metal ion. In addition to tetrahydrofuran and tetrahydropyran rings, other groups which are often present include spiroketal, dispiroketal, and substituted benzoic acid moieties and
30 occasionally other groups for example a tetronic acid or

a 6-membered carbocyclic ring

Monensins A and B are produced by the actinomycete *Streptomyces cinnamonensis*. Their structures are shown in Figure 1. Monensin B differs from monensin A only in the presence of a methyl sidechain at C-16 rather than an ethyl sidechain. Monensin selectively binds and transports sodium ions. In addition to its antibacterial and antifungal properties monensin has some activity against protozoal parasites such as the malarial parasite *Plasmodium falciparum*. Although the structures of polyethers differ significantly from those of other complex polyketides such as the polyhydroxylated and polyene macrolides, their biosynthesis appears to take place by a metabolic pathway which has many common elements. Thus experiments using carbon 14-labelled precursors have shown that monensin A is synthesised from five acetate, one butyrate and seven propionate units (Day, L.E. et al. Antimicrob. Agents Chemother. (1973) 4:410-414). Similarly experiments using precursors doubly-labelled with carbon-13 and oxygen-18 have shown that oxygens (O)1, (O)3, (O)4, (O)5, (O)6 and (O)10 of monensin arise from the carboxylate oxygens of either propionate or acetate, while growth in the presence of oxygen-18 oxygen gas demonstrated that the three remaining ether oxygens (O)7, (O)8 and (O)9 are derived from molecular oxygen (Cane, D.E. et al., J. Am. Chem. Soc. (1981) 103:5962-5965; Cane, D.E. et al. J. Am. Chem. Soc. (1982) 104:7274 - 7281; Ajaz, A.A. and Robinson, J.A. J. Chem. Soc. Chem. Commun. (1983) 12:679-680). These findings have been rationalised by proposing that

the biosynthesis of monensin proceeds via an acyclic triene intermediate (1) in which the geometry of all three carbon-carbon double bonds is E (entgegen) rather than Z (zusammen). The triene is then proposed to be
5 subject to epoxidation to a tri-epoxide (2) and then ring opening is proposed to occur with concomitant sequential formation of the five ether rings as shown in Figure 2A. Such a biosynthetic pathway, first mooted by Westley in 1974 (Westley J.W. et al., J. Antibiot. (1974) 27:597-
10 604) accounts for the observed stereochemistry at the multiple asymmetric centres in monensin, (Cane, D.E. et al. J. Am. Chem. Soc. (1982) 104:7274-7281; Sood, G.R. et al. J. Chem. Soc. Chem. Commun. (1984) 21:1421-1424) and analogous schemes can be used to account for the
15 biosynthesis of other known polyethers. such as lasalocid A (Hutchinson C.R. et al., J. Am. Chem. Soc. (1981) 103:5953-5956), tetronasin (ICI 139603) (Demetriadou, A.K. et al. J. Chem. Soc. Chem. Commun. (1985) 7:408-410) and narasin (Spavold, Z. et al. Tetrahedron Letters
20 (1986) 27:3299-3302). The hydroxylation at C-26 and the introduction of an O-methyl group on oxygen 3 are proposed to occur as late steps in the biosynthesis, after formation of the polyether structure.

Unfortunately key aspects of the biosynthetic scheme
25 shown in Figure 2A have so far eluded experimental confirmation. No biosynthetic intermediates have been isolated from mutants of *S. cinnamomensis* that are blocked in early stages of monensin production. 26-deoxymonensin A has been isolated from a *S. cinnamomensis*
30 mutant partially blocked in monensin production

(Ashworth, D.M. et al. J. Antibiot. (1989) 42:1088-1099) and 3-0-demethylmonensins A and B have been recovered as minor components from the fermentation broth of a monensin-producing strain (Pospisil, S. et al. J. Antibiot. (1987) 40:555-557). When fed to cells of *S. cinnamonensis* in radio-labelled form, neither 26-deoxymonensin A, nor 3-0-demethylmonensin A, nor 3-0-demethyl, 26-deoxymonensin A were significantly incorporated into monensin A (Ashworth, D.M. et al. J. Antibiot. (1989) 42:1088-1099), either because they are actively excluded or because these modifications in fact occur earlier in the biosynthetic pathway so that these metabolites are shunt products not readily converted into the final antibiotic by the respective hydroxylase or methyltransferase. Similarly, the putative all (E)-triene precursor (1) has been synthesised and shown not to become incorporated into monensin when fed to growing cells of *S. cinnamonensis* (Holmes, D.S. et al. Helv. Chim. Acta (1990) 73:239-259). An alternative pathway has been proposed, as shown in Fig 2B, based on the transition-metal-mediated oxidation of 1,5-dienes (Walba, D.M. and Edwards, P.D. Tetrahedron Lett. (1980) 21:3531-3534). The triene intermediate (4) would differ from that of Figure 2A (1) only in that each carbon-carbon double bond would have the (Z)-configuration (Townsend, C.A. and Basak, A. Tetrahedron (1991) 47:2591-2602) and not the (E)- configuration.

The genetic basis of secondary metabolite biosynthesis essentially exists in the genes which code for the individual biosynthetic enzymes and in the

regulatory elements which control the expression of the biosynthetic genes. The genes encoding biosynthesis of polyketides in actinomycetes have hitherto been found as clusters of adjacent genes, ranging in size from
5 20 kilobasepairs (kbp) to over 100 kbp. The clusters often contain specific regulatory genes and genes conferring resistance of the producing strain to its own antibiotic.

10 In various of its aspects the invention provides the following:-

(1) a DNA sequence encoding at least one peptide necessary for the biosynthesis of monensin, preferably comprising one or more of the following genes: *mon BI*, *mon BII*, *mon CI*, *mon CII*, *mon H*, *mon RI*, *mon RII*, *mon T*,
15 *mon AIX* and *mon AX* as depicted in the appended sequence data or an allele or mutation thereof;

(2) a DNA sequence according to the first aspect comprising all of the genes listed therein or an allele or mutation thereof;

20 (3) a DNA sequence according to the first aspect comprising the complete monensin gene cluster;

(4) a DNA sequence coding for one or more of the peptides set out below, said peptide having the amino acid sequence as set out in the appended sequence data or
25 being a variant thereof having the specified activity:

<u>peptide</u>	<u>activity</u>
<i>mon CII</i>	epoxyhydrolase/cyclase
<i>mon E</i>	S-adenosylmethionine-dependent methyltransferase
<i>mon T</i>	monensin resistance gene
30 <i>mon RII</i>	repressor protein

	<i>mon AIX</i>	thioesterase
	<i>mon AI</i>	polyketide synthase multienzyme
	<i>mon AII</i>	polyketide synthase multienzyme
	<i>mon AIII</i>	polyketide synthase multienzyme
5	<i>mon AIV</i>	polyketide synthase multienzyme
	<i>mon AVI</i>	polyketide synthase multienzyme
	<i>mon AVII</i>	polyketide synthase multienzyme
	<i>mon AVIII</i>	polyketide synthase multienzyme
	<i>mon H</i>	regulatory protein
10	<i>mon CI</i>	flavin-dependent epoxidase
	<i>mon BII</i>	carbon-carbon double bond isomerase
	<i>mon BI</i>	carbon-carbon double bond isomerase
	<i>mon D</i>	cytochrome P450 hydroxylase
	<i>mon RI</i>	activator protein
15	<i>mon AX</i>	thioesterase

(5) a recombinant cloning or expression vector comprising a DNA sequence according to any of aspects 1-4;

(6) a transformant host cell which has been transformed to contain a DNA sequence according to any of aspects 1-4 and is capable of expressing a corresponding peptide;

(7) a hybridization probe comprising a polynucleotide which binds specifically to a region of the monensin gene cluster selected from *mon BI*, *mon BII*, *mon CI*, *mon CII*, *mon H*, *mon RI*, *mon RII*, *mon T*, *mon AIX* and *mon AX*;

(8) use of a probe according to aspect (7) in a method of detecting the presence of a gene cluster which governs the synthesis of a polyether, and optionally

isolating a gene cluster detected thereby;

(9) Use of a probe comprising a polynucleotide which binds specifically to a gene responsible for levels of activity of the monensin gene cluster, preferably a regulatory gene, resistance gene or thioesterase gene,
5 more preferably the regulatory gene *mon RI*, in a method of detecting an analogous gene in a gene cluster of another polyketide, preferably a polyether, and optionally manipulating the gene detected thereby to alter the level
10 of expression of said other polyketide;

(10) a host cell, preferably *Streptomyces cinnamonensis*, containing a heterologous gene under the control of the *mon RI* gene and a monensin promoter;

(11) use of a portion of the monensin gene cluster
15 having chain terminating activity, preferably comprising at least one of *mon AIX* and *mon AX* or a mutant or allele thereof having chain terminating activity, to effect chain release of a peptide other than one required for monensin biosynthesis;

(12) use of a portion of the monensin gene cluster
20 having carbon-carbon double bond isomerase activity, preferably comprising at least one of *mon BI* and *mon BII* or a mutant or allele thereof having isomerase activity to provide a desired stereochemical outcome in the synthesis
25 of a polyketide other than monensin;

(13) a polypeptide encoded by a portion of the monensin gene cluster, preferably comprising at least one of *mon BI* and *mon BII* or a mutant or allele thereof, having carbon-carbon double bond isomerase activity;

30 (14) an epoxidase enzyme encoded by *mon CI* or a

derivative or variant thereof having epoxidase activity;

(15) a cyclase enzyme encoded by *mon CII* or a derivative or variant thereof having cyclase activity.

Some embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:

Fig 1 shows the structure of monensins A and B;

Fig 2 illustrates proposed biosynthetic pathways;

Fig 3 illustrates the proposed organization of the monensin polyketide synthase (PKS) enzyme complex; and

Fig 4 illustrates the proposed organization of the monensin biosynthetic gene cluster.

The overall gene organization of the monensin biosynthetic gene cluster, as shown in Fig 4, is similar to that previously found for many macrolide biosynthetic gene clusters, which have one or more open reading frames (ORFs) encoding large multifunctional PKSs flanked by other genes which encode functions required for the biosynthesis of the antibiotic. In the case of monensin, there is an unusually high number of distinct ORFs encoding PKS multi-enzymes (eight in total, labelled *monAI* to *monAVIII*) but there is again a separate module of enzymes for each cycle of polyketide chain extension, exactly as found for modular PKSs for macrolide biosynthesis (see Fig 3). Thus there are 12 condensations predicted to be required for the production of the carbon skeleton of monensin, and in agreement with this there are found to be 12 extension modules of PKS enzymes distributed among the 8 PKS ORFs. However, as mentioned in detail below, the other genes in the monensin cluster

include genes which have not previously been found in any other gene cluster for the biosynthesis of a complex polyketide, and which are not significantly similar to any genes in published sequence databases. The cloned DNA for these genes is useful to allow the diagnosis that a polyketide biosynthetic gene cluster in any actinomycete, uncovered previously by conventional hybridization against a PKS gene probe from (say) the DEBS or some other characterised PKS gene cluster, is one that governs the synthesis of a polyether; and these genes are also valuable either singly or in combination as specific hybridization probes for the specific detection and isolation of additional polyether biosynthetic gene clusters. Examples of these previously-unknown genes are the genes *monBI*, *monBII*, *monCI* and *monCII*. In addition the regulatory genes *monH*, *monRI*, and *monRII* and the resistance gene *monT* and the thioesterase genes *monAIX* and *monAX* are all useful for the detection of analogous genes in other polyether clusters which are required for the rational manipulation of such genes in order to increase levels of the specific product.

The cloned and sequenced cluster of genes for monensin biosynthesis is useful secondly in the engineering of mutant strains of *S. cinnamonensis* and of other actinomycetes which are suitable strains for the high level production of either natural or novel recombinant polyketides. The sequence of the monensin cluster disclosed here shows the surprising fact, that the gene cluster contains a gene *monRI* whose gene product has an amino acid sequence highly similar to that of *actII*-

orf4, the pathway-specific activator gene which activates the *actI* and other promoters of the actinorhodin biosynthetic gene cluster of *Streptomyces coelicolor*. The recognition of this aspect of the natural regulation of a Type I PKS cluster is important and valuable because first, as will be immediately obvious to the person skilled in the art, it will be possible to increase the yield of monensin by increasing the level of the activator MonRI, either by placing the gene *monRI* under the control of a powerful promoter or arranging for the presence within the cells of one or more additional copies of the *monRI* gene; secondly, it will be possible to use the *monRI* gene as a specific hybridisation probe to locate similar genes in other complex PKS gene clusters, especially other polyether PKS gene clusters but also polyene and macrolide gene clusters and all other Type I modular PKS gene clusters; even in cases where (as for rapamycin and erythromycin) no such gene has been previously found within the currently accepted physical limits of the relevant biosynthetic gene cluster. In such cases the *monRI* gene probe might be expected to uncover the activator even if it resides on the chromosome at some distance from the main body of the gene cluster; and simple experiments would then show whether the activator(s) so uncovered are involved in regulation of the biosynthesis of those particular metabolites; thirdly, increasing the copy number of the *monRI* gene or of any of the activator genes uncovered will tend to increase the yield of a heterologous polyketide by "crosstalk" where the activator mimics the presence of the normal activator

for the transcription of the genes for that heterologous polyketide synthase. It is clear from recently published work (Wietzorrek, A. and Bibb, M. Mol. Microbiol. (1997) 25:1181-1184) that the ActII-orf4 family of activators
5 exert their effects by binding to promoter regions within the target gene cluster, so it will be possible to use the *monRI* gene together with monensin promoter regions to drive the high-level transcription and translation of heterologous genes in *Streptomyces cinnamomensis*, and
10 perhaps in other host strains too; such genes need not be PKS genes or even involved in polyketide biosynthesis. Monensin promoter regions are found at the 5' end of genes or groups of genes in the cluster and their location is clear from the sequence analysis disclosed here. Thus a
15 useful vector would provide the monensin promoter and the ribosome binding site and continue up to the start of the open reading frame, after which the monensin ORF naturally found there would be replaced by the heterologous gene. The relative strength of the monensin promoters can be
20 readily determined using any one of a number of known promoter probes, i.e. genes whose expression gives rise to readily measurable and quantifiable effects, such as Green Fluorescent Protein (GFP); or beta-galactosidase in the presence of a chromogenic substrate. It should be possible
25 to mutate randomly the small region of the monensin promoters especially likely to interact with the MonRI activator (identified by the presence of tandem heptanucleotide repeats with a common consensus sequence between the various monensin promoters) (Wietzorrek, A.
30 and Bibb, M. Mol. Microbiol. (1997) 25:1181-1184), and to

determine the optimal DNA sequence for the maximal
activation effect using either *S. cinnamonensis*
(preferably - in case there are other unknown factors that
make the activation function better in this strain than in
5 other heterologous systems), or even in another host
actinomycete strain. If the natural monensin promoters
were mutated to have this optimal recognition sequence,
then this would further increase the production of
monensin. By extension, the use of this modified monensin
10 promoter in conjunction with the *monRI* gene in
heterologous systems could form the basis of further
improvements in expression of polyketide synthases or
other genes, either by appropriate chromosomal alterations
to introduce the altered promoter and also the *monRI* gene;
15 or by provision of vectors containing these optimised
signals linked to specific genes and housed in suitable
host cells.

The sequencing of the monensin cluster has uncovered
another strategy for gene regulation in such Type I
20 clusters. The previously-sequenced genes for the rapamycin
biosynthetic pathway in *Streptomyces hygroscopicus*
included a gene of unknown function (*rapH*). A closely
similar gene has now been found in the monensin
biosynthetic gene cluster (*monH*), and it is clear from
25 this recurrence (and the comparison of the sequences with
those of database proteins) that this gene is potentially
an important DNA-binding sensor gene which acts to
regulate the transcription of the cluster in concert with
other regulatory signals. Simple experimentation is needed
30 in order to define whether the gene is an activator, in

which case putting in another copy or increasing its transcription will have the potential to increase polyketide biosynthesis; or alternatively the *rapH* gene product may be a negative regulator, whereupon deletion of this gene may release the biosynthetic pathway from this inhibitory effect and increase yields.

There is a continuing need to develop new methods of high-level production of bioactive metabolites and other valuable gene products in actinomycetes. *Streptomyces* *cinnamomensis* is a recognised and very valuable industrial strain for the production of very high levels of monensin, it is readily transformable with DNA by standard methods of conjugation or of protoplast transformation, it is a host for numerous known broad range plasmids including well-known expression plasmids of both high- and low-copy number, it also grows quickly relative to other actinomycete strains (for example about three times faster than wild type *Saccharopolyspora erythraea* the erythromycin producer, under comparable conditions) and sporulates relatively easily. Heterologous polyketides can be expressed in *Streptomyces cinnamomensis* using for example the low-copy number plasmid pCJR24 (which has no origin of replication active in actinomycetes so is maintained by integration into the chromosome) (Rowe, C. et al. Gene (1998) 216:215-223) or the related plasmid pCJR29 in which the polyketide synthase gene(s) are placed under the control of the *actI* promoter which is activated by the ActII-orf4 activator; or alternatively the *monAI* promoter can be substituted together with the MonRI activator; or some other pairing of activator and cognate

promoter chosen from either a Type II or a Type I polyketide synthase gene cluster. As an example, the wild type strain of *Streptomyces cinnamonensis* has been used to express the plasmid pCJR29 (Rowe, C. et al. Gene (1998) 216:215-223) containing as insert the three ORFs for the PKS governing the production of 6-deoxyerythronolide B, the macrolide precursor of erythromycin A in *Saccharopolyspora erythraea*, these genes being placed under the control of the pathway-specific *actI* promoter from *Streptomyces coelicolor* together with its cognate activator gene *actII-orf4*. The transformed strain when cultivated in a suitable liquid medium produced 6-deoxyerythronolide B in good yield.

It is well known to the person skilled in the art that it is possible to use standard vectors unable to replicate in actinomycetes to introduce DNA into a *Streptomyces* cell, such DNA comprising two portions of contiguous DNA which are each identical to one of two portions of the cell's chromosome that are spaced up to 100 kbp apart; and that through recombination between the incoming DNA and the chromosome occurring in both portions of DNA the net result is that the chromosomal sequence is replaced by the defective sequence originally that of the incoming DNA. Such a procedure has been applied to the monensin-producing strain of *S. cinnamonensis* as described in detail below, and a strain of *S. cinnamonensis* has been obtained that carries a specific deletion in the monensin cluster and which is unable to produce the antibiotic. The use of such a strain facilitates the production of heterologous polyketides by removal of the background of

monensin production.

The multiple uses of portions of the cloned and sequenced DNA from the monensin cluster will readily occur to the person skilled in the art. A surprising feature of the PKS of the monensin cluster is an unusual mechanism of polyketide chain initiation. We have found that the monensin PKS loading module has three domains, which from the amino-terminus of the protein are: a KSq domain, an acyltransferase domain and an ACP domain. We have uncovered this organisation in the PKS for the 14-membered macrolide oleandomycin as well as in the monensin PKS, an organisation of the loading module previously only found for the 16-membered macrolides and in which the KSq domain (which looks like a ketosynthase or condensation domain except that the active site cysteine residue is substituted by a glutamine for which the single letter notation is Q) had been previously speculated to have no function. It was realised that the acyltransferase of the loading module actually has malonyl-CoA and not acetyl-CoA as a substrate and that KSq is an active decarboxylase. It appears that a better discrimination can be achieved in the selection of the smaller acetate unit over propionate if the choice is made initially between methylmalonyl- and malonyl-CoA.

An unprecedented feature of the monensin PKS genes is that no integral chain-terminating domain is present as a C-terminal appendage of the PKS extension module that catalyzes the twelfth and final chain extension. Because the product of the monensin PKS is a carboxylic acid, it would have been firmly predicted that chain release would

have been catalyzed by such a C-terminal domain containing a "thioesterase" activity. Previously sequenced PKS gene sets have been of two sorts: first, those macrolide PKSs typified by erythromycin, spiramycin, tylosin, niddamycin
5 which have a readily recognisable C-terminal "thioesterase" domain, which in these enzymes functions as a specific cyclase rather than releasing the polyketide product as a free carboxylic acid; secondly, those macrolide PKSs typified by rapamycin, FK506, and
10 rifamycin, where there is an alternative and recognised mode of chain termination by transfer of the polyketide chain to an acceptor moiety, catalyzed by a specific enzyme (eg pipecolate incorporating enzyme for rapamycin (Schwecke T. et al. Proc. Natl. Acad. Sci. USA (1995)
15 92:7839-7843) and FK506 (Mothamedi H. and Shafiee A, Eur. J. Biochemistry (1998) 256:528-534); arylamine synthetase for rifamycin (August P.R. et al. Chemistry & Biology (1998) 5:69-79).

The monensin PKS surprisingly falls into neither
20 category, and therefore seems to be the first example of a novel mode of chain termination. It is novel and noteworthy in this connection that the monensin PKS gene cluster contains two small genes that encode discrete, monofunctional thioesterase enzymes. Although many PKS
25 gene clusters have been previously shown to contain one such discrete thioesterase, none have been shown to have two. The role of such thioesterases is not known, although in the case of methymycin/pikromycin PKS, which has been reported to be responsible for the biosynthesis of both
30 the 12-membered macrolide methymycin and the 14-membered

macrolide pikromycin (Xue Y.Q. Proc. Natl. Acad. Sci. USA
(1998) 95:12111-12116) the disruption of this thioesterase
reportedly caused a ten-fold drop in the amount of both
macrolides produced. A similar finding has been reported
5 for the discrete thioesterase of the tylosin PKS gene
cluster (Cundliffe E. et al. Chemistry & Biology in
press). Additional copies of such thioesterases may
therefore accelerate the production of specific
polyketide, but this has not yet been demonstrated.
10 However, the presence of the discrete thioesterase is not
completely essential for polyketide production.

It is highly desirable to have a broadly effective
method of catalysing the release of polyketide gene
products from a PKS as the free acid. The well-studied
15 integral thioesterase domain in the erythromycin PKS
thioesterase has a broad specificity in cyclization to
form a lactone (assuming that a hydroxy group is present
in the growing polyketide chain at an appropriate
position), but hydrolysis to form the free acid is very
20 slow. The recognition of the unusual arrangement of the
monensin PKS means that it is now possible to harness
either the entire PKS module that catalyses the twelfth
and final extension cycle in monensin biosynthesis, or the
C-terminal portion of it, and graft it onto a different
25 polyketide synthase by genetic engineering, so as to allow
the release mechanism characteristic of monensin to
operate in a different context. The use of this portion
only of the monensin PKS suffices to allow the novel
mechanism of chain release to operate successfully. The
30 speed of the polyketide chain hydrolysis in a given case

can depend on the additional presence of one or both of the discrete thioesterase genes (*monAIX* and *monAX*) from the monensin gene cluster. The use of this novel method of chain termination represents a valuable way of generating a large number of novel engineered polyketides that are currently inaccessible, and ensuring that the products have a specified chain length.

The genes *monBI* and *monBII* appear to encode very similar enzymes with significant amino acid sequence similarity to authentic ketosteroid isomerases which are known to catalyse the migration of an activated carbon-carbon double bond. The conservation of active site residues makes it very likely that these *mon* genes govern a reaction involving activated double bonds in the biosynthetic pathway to monensin and this surprising observation can be accommodated if the initial product of the polyketide chain growth on the monensin PKS is a linear precursor in which the double bonds were initially formed with a conventional *trans* or *E* (*entgegen*) geometry; but before the polyketide chain was extended by insertion of the next unit the *monBI* and/or the *monBII* gene product(s) catalyse the specific rearrangement of the newly-created double bond into the *cis* or *Z* (*zusammen*) geometry. This new view of the monensin biosynthetic pathway allows the deduction that the *monBI* and *monBII* genes, perhaps in combination with specific portions of the monensin modules where they normally exert their effects (namely modules 3, 5 and 7) might be used in order to achieve the extremely desirable targetted biosynthesis of novel polyketides containing double bonds with *Z*

geometry at specified point(s) along the chain. Thus for example it should be possible to provide for the direct biosynthesis of C22-C23 *cis* or *Z* double bond in avermectins, thus avoiding tedious and expensive chemical conversion of an initial fermentation product into this important anthelmintic. Only limited experimentation is needed to see whether the *monBI* and/or *monBII* gene products are sufficient or whether the *mon* PKS at modules 3, 5 and 7 forms part of the specific docking site(s) for the isomerases and therefore must also be used in the creation of the hybrid PKS that will insert the *cis* or *Z* double bond at the desired position. The substrate specificity of the isomerases need not be limited to 2,3-unsaturated thioesters. The purified enzymes could also be used to effect such isomerisations *in vitro*, depending on the position of the equilibrium or whether further enzymes are used to achieve the further transformation of the product as it is formed (*vide infra*).

The product of the *monCI* gene is a novel oxidative enzyme with some sequence similarity to authentic examples of such enzymes in the databases; and with a clearly definable role in the monensin biosynthetic pathway, the epoxidation of the double bonds at three separate positions in the initially-formed acyclic intermediate in monensin biosynthesis. This epoxidase could therefore be used in conjunction with *monBI/monBII* gene products to effect oxidative reactions on suitable substrates *in vitro* and *in vivo*. Similarly the *monCII* gene product is a putative cyclase that opens the epoxides and causes the formation of ether rings in monensin.

Any or all of the *monBI*, *monBII*, *monCI* or *monCII* genes may be introduced into a heterologous strain containing the gene cluster for another polyether, in order to divert the biosynthetic pathway and produce a polyketide of altered structure. In these experiments the analogues of these *monB* genes could either be present or (once located and characterised using the *mon* genes as probes) they may be deleted prior to the introduction of the *monB* and *monC* genes into that strain. The converse experiment in which analogues of the *monB* and *monC* genes from other strains are introduced into *S. cinamonensis* likewise has the potential to produce novel oxidised polyketides. Also, the *monB* and *monC* genes or their analogues may be introduced into a strain that normally produces a macrolide or a polyene or some other complex polyketide and expressed there, when they may effect the diversion of the growing polyketide chain on a heterologous modular PKS towards a new product, which may or may not have the structure of a polyether.

The availability of the monensin gene sequence allows the institution of domain swaps to alter the acyltransferase (AT) specificity of a given module, for example the ethylmalonyl-CoA specific extender found in one of the modules of the monensin PKS can be used to replace one of the other ATs to generate an ethyl side branch at that position in the chain, or the AT can be used to substitute in any other (e.g. macrolide) PKS, as described in WO 98/01571 and WO 98/01546. Similarly the alteration of the level of reduction in a module, by

manipulation of the reductive enzymes, can be applied to the monensin genes and here it will produce, depending on which module is affected, either an altered monensin, or a species which is only partly cyclised, or a polyether with an altered pattern of cyclisation, or even a linear polyketide.

In general the targetted alteration of the pattern of substitution of sidechains or reduction level along the polyketide chain produced by the monensin PKS will, like the disruption or deletion of the oxidative enzymes mentioned above, lead to non-polyether polyketide products. It should be possible, by introduction of the DEBS thioesterase at the C-terminus of one of the later modules of the monensin PKS, together with an appropriately placed hydroxy group earlier in the chain, to produce novel macrolide products from this polyether PKS system, or alternatively novel polyenes of defined chain length and chosen ring size.

Example 1

Cloning of the monensin A biosynthetic gene cluster using
DNA probes derived from the erythromycin-producing
polyketide synthase of *Saccharopolyspora erythraea*

5 A genomic library of the monensin A producing strain
Streptomyces cinnamonensis ATCC 15413 was constructed
using methods well-known in the art, namely, the
production of high molecular weight genomic DNA, followed
by the partial cleavage of this DNA using the frequent-
10 cutting restriction enzyme *Sau*3A, fractionation of the
fragments on a sucrose gradient and selection of fragments
of average size 35-40 kbp, and the cloning of these
fragments into the cosmid vector pWE15 (Evans, G.A. et al.
Gene (1989) 79:9-20) which had been previously digested
15 with *Bam*HI and treated with shrimp alkaline phosphatase.
The library was packaged and transfected into *Escherichia*
coli XL-1 Blue MR cells. The library was plated out on
2xTY agar medium (10 g tryptone, 10 g yeast extract, 5 g
NaCl, 15 g bactoagar per litre containing ampicillin 50
20 μg/ml) for cosmid selection and the colonies were allowed
to grow overnight. The library was then screened by
hybridisation using as a probe DNA encoding the
ketosynthase domain of module 1 of the erythromycin-
producing PKS (6-deoxyerythronolide B synthase, DEBS) of
25 *Saccharopolyspora erythraea*. The colonies giving a
positive hybridisation signal in the hybridisation were
selected and the cosmid DNA from each colony was purified
and mapped by restriction digestion. The presence of the
target biosynthetic genes on a cosmid was verified by
30 sequencing of the ends of the cosmid inserts using the

commercially available T3 and T7 primers which hybridise specifically to the respective ends of each cosmid insert (Evans, G.A. et al. Gene (1989) 79:9-20).

Example 2

5 Sequencing of the biosynthetic gene cluster for monensin A
 from *Streptomyces cinnamonensis*

Three cosmids obtained by screening of the genomic library of *S. cinnamonensis* were used to obtain the entire DNA sequence of the monensin biosynthetic gene cluster.

10 These cosmids, MO.CN02, MO.CN11 and MO.CN33 between them contain the entire DNA sequence of the cluster and the adjacent regions of the chromosome. They have been deposited in NCIMB, 23 St Machair Drive, Aberdeen AB24 3RY, UK, under the NCIMB accession numbers 40956
15 (MO-CN11); 40957 (MO-CN33) and 40958 (MO-CN02) respectively.

The DNA of each cosmid was separately subjected to partial digestion with *Sau3A* and fragments of approximately 1.5-2.0 kbp were separated by agarose gel
20 electrophoresis. The fragments were then ligated into the plasmid vector pUC18 (Messing, 1982), previously digested with *Bam*HI and treated with shrimp alkaline phosphatase. The library was transformed into *E. coli* strain XL1-Blue MR and plated on 2xTY agar medium containing ampicillin
25 (100 µg/ml) to select for plasmid-containing cells. Plasmid DNA was purified from individual colonies and sequenced using the Sanger dye-terminator procedure on an ABI 377 automated sequencer (Sanger, F. Science (1981) 214:1205-1210). The sequence data obtained from single
30 random subclones of a cosmid was assembled into a single

continuous sequence and edited using GAP4.1 program of the STADEN gene analysis package (Staden, R. Molecular Biotechnology (1996) 5:233-241).

The sequence is set out in the appended sequence listing.

Tables I and II contain data about individual genes and gene products.

Example 3

Inactivation of the monensin A biosynthetic gene cluster

A chromosomal gene disruption experiment was used to verify the identity of the cloned polyketide synthase gene cluster. Plasmid pMOB6314 is a pUC18 sequencing subclone of the presumed monensin A biosynthetic gene cluster prepared as described in Example 1, whose inserted DNA comprises the DNA sequence from nucleotide 9763 to nucleotide 10108 in SEQ ID 1, and which therefore contains a region of DNA wholly internal to *orfE*, a putative 3-O-methyltransferase. A *Hind*III fragment containing the thiostrepton resistance gene *tsr* from plasmid pIJ702 (Katz, E. et al. J. Gen. Microbiol. (1983) 129:2703-2714) was cloned into the *Hind*III site of plasmid pMOB6314 and the ligation mixture was used to transform *E. coli* cells. Transformants bearing the required plasmid pMOΔE01 were identified by isolation of plasmid DNA and analysis by restriction digestion. pMOΔE01. Plasmid pMOΔE01 was used to transform protoplasts of *Streptomyces cinnamonensis* as described by (Hopwood D.A. et al. (1985)). Since plasmid pMOΔE01 lacks an origin of replication that is active in *Streptomyces*, growth in the presence of thiostrepton (25 μg/ml) in the regeneration medium led to the isolation of

stable integrants. Isolated putative integrants were tested for the presence of integrated pMOΔE01 sequences by Southern hybridisation. A clone of *Streptomyces cinnamonensis* identified by its restriction pattern in
5 Southern hybridisation as bearing pMOΔE01 integrated in the region of *monE* of the monensin A biosynthetic gene cluster was designated *S. cinnamonensis* MO-DD01.

Detection of production of the monensin A related metabolites produced by *S. cinnamonensis* MO-DD01 was
10 performed by GC-MS analysis of methanol extracts of the entire broth harvested in 72 hours of growth of the strain. No significant amounts of monensin A-related metabolite production were detectable.

Example 4

15 Overproduction of erythromycin aglycone in *Streptomyces cinnamonensis*

S. cinnamonensis is a suitable system for overproduction not just of monensin A but also of other polyketide metabolites. Established techniques of genetic
20 transformation allow fast introduction of foreign polyketide producing genes sets into this host. Fast growth of *S. cinnamonensis* in liquid culture and optimal precursor supply favour high yield of polyketide metabolites.

25 Protoplasts of *S. cinnamonensis* were prepared by a modified procedure of Hopwood et al. (1985). Plasmid pIB061 was transformed into the protoplasts of *S. cinnamonensis* and stable thiostrepton resistant colonies were isolated. Individual colonies were checked for their

plasmid content and the presence of plasmid pIB061 was confirmed by its restriction pattern. *S. cinnamonensis* (pIB061) was inoculated into 250 ml of M-C3 minimal production medium containing 10 μ g/ml of thiostrepton and allowed to grow for 72 hours at 30 °C. After this time the mycelia were removed by filtering. The broth was extracted with two volumes of ethyl acetate and the combined ethyl acetate extracts were washed with an equal volume of saturated sodium chloride, dried over anhydrous sodium sulphate, and the ethyl acetate was removed under reduced pressure to give about 200 mg of crude product. The product was analysed by LCQ and mass was confirmed to that of erythronolide B.

This example demonstrates the importance of *S. cinnamonensis* for production of high levels of foreign polyketide antibiotics. Introduction of the complete erythromycin gene cluster or other gene clusters into this system are likely to produce high levels of the corresponding metabolites.

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93351 TCTCCAGGGC GAGCCGCTGC TGCGGCGCCA TGGCCGCGGC CTCGGTGGGT
93401 CCGATGCCGA AGAAGGTGGG GTCGAAGTCA CCGGCGTCGT AGACGAAGCC
93451 GCCTTCCCGG ACGTAACTGG TGCCGGTGCT CTCGGGGTCC GGGTCGTAGA
93501 GGGAAATCGAG GTCCCAGTTG CGGTTGCCGG GCAGGGGCGC GACGGCGTCG
93551 CCGCCGGTGG AGACCAGCTC CCAGAACTCT TCGGGAGACC GGACTCCGCC
93601 GGGCAGCCGG CAGGCCATGC CGATGACCGC GACCGGTTCC TGGCCCGCCG
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93751 AACCGCCCCT CTCCGCGAGA ACAGACCGCA GACTCGTCGA CGGCGCTAAA

93801 GCCCTCCTAA TACTCGGCTG TGTACCGCTC GCTGCCACGG GTGTCCGCAC
93851 TGGTCGGAGG CTCCGGCCCA GGGAACAGGG GCTTTCTTAG GGGCGCTTAA
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93951 GGCCTCGCCC GTGCCGTGCC CGTGCGGTGCG GTGGGCCTGA CCGTCGGTCC
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Table 1

positions_all

gene	function	start	end
gdhA	glutamate dehydrogenase (partial)	1038	0
dapA	dihydrodipicolinate synthase	2140	1220
orf3	putative transcriptional activator	2211	3152
orf4	hypothetical protein	3264	3680
orf5	hypothetical protein	4307	3684
orf6	hypothetical protein	4570	4758
orf7	hypothetical protein	5058	5612
acpX	acyl carrier protein	6010	5693
ksX	ketoacyl synthase	8531	6045
monCII	probable epoxihydrolase/cyclase	9542	8643
monE	methyltransferase	10426	9596
monT	monensin resistance gene (ABC-transporter)	10656	12191
monRII	probable repressor	12205	12780
monAIX	thioesterase	13829	13023
monAI	polyketide synthase loading & module 1	14121	23198
	KS-L	14172	15486
	AT-L malonate specific	15777	16880
	ACP-L	17019	17276
	KS1	17358	18626
	AT1 methylmalonate specific	18960	19976
	DH1 (potential)	20019	20519
	KR1 (inactive)	21636	22241
	ACP1	22536	22793
monAII	polyketide synthase module 2	23205	29921
	KS2	23307	24569
	AT2 methylmalonate specific	24891	25913
	DH2	25953	26369
	ER2	27600	28463
	KR2	28485	29042
	ACP2	29313	29570
monAIII	polyketide synthase modules 3 & 4	29974	42372
	KS3	30076	31347
	AT3 malonate specific	31798	32838
	DH3	32884	33465
	KR3	34692	35181
	ACP3	35553	35811
	KS4	35899	37170
	AT4 methylmalonate specific	37489	38511
	DH4	38557	38982
	ER4	40123	40986
	KR4	41005	41562
	ACP4	41848	42105
monAIV	polyketide synthase modules 5 & 6	42448	54564
	KS5	42628	43890
	AT5 ethylmalonate specific	44221	45243
	DH5	45289	45744
	KR5	46785	47337
	ACP5	47593	47850
	KS6	47947	49218

	AT6 malonate specific	49579	50601
	DH6	50644	51075
	ER6	52222	53102
	KR6	53101	53661
	ACP6	54052	54306
monAV	polyketide synthase modules 7 & 8	54614	66934
	KS7	54716	55978
	AT7 methylmalonate specific	56300	57319
	DH7	57358	57802
	KR7	59048	59608
	ACP7	59867	60124
	KS8	60185	61453
	AT8 malonate specific	61808	62839
	DH8	62882	63316
	EP8	64577	65437
	KR8	65456	66016
	ACP8	66404	66661
monAVI	polyketide synthase module 9	66952	72054
	KS9	67075	68340
	AT9 malonate specific	68698	69729
	KR9 (potential)	70735	71262
	ACP9	71536	71783
monH	probable regulator	72051	74993
monCI	FAD containing epoxidase	76541	75051
monBII	double bond isomerase	76960	76538
monBI	double bond isomerase	77450	77016
monAVIII	polyketide synthase modules 11 & 12	88708	77447
	KS11	88612	87344
	AT11 methylmalonate specific	87022	85993
	KR11	85111	84562
	ACP11	84292	84035
	KS12	83962	82694
	AT12 methylmalonate specific	82354	81335
	DH12 (potential) delta	81286	80855
	ER12 (potential)	79618	78914
	KR12	78895	78337
	ACP12	78070	77812
monAVII	polyketide synthase module 10	93741	88816
	KS10	93636	92368
	AT10 methylmalonate specific	92040	91021
	KR10	90132	89584
	ACP10	89322	89068
monD	P450 oxygenase	94081	95273
monRI	probable activator	96141	95338
monAX	thioesterase	96941	96138
orf29	cell wall biosynthesis capK homologue	97580	98953
lipB	lipase B	99983	98991
orf31	ion pump	101433	100507
orf32	membrane structural protein	102581	101490
amtA	glycine amidinotransferase	102924	103450

- ble II

GdhA, glutamate dehydrogenase (partial coding sequence) Length: 346 amino acids

```
1  LTTRPDTKTA LSQKTALSQ L TEIEHRNPA QPEFHQAARE VLETLAPVIA
51  ARPEYAEAGL IERLCEPERQ IVFRVPWQDD HGRVRVNRGF RVEFNSALGP
101 YKGGLRFHPS VNLGVIFLG FEQIFKNALT GLGIGGGKGG SDFDPRGRSD
151 AEVMRFCQSF MTELYRHIGE HTDVPAGDIG VGGREIGYLF GQYRRITNRW
201 EAGVLTGKGR NWGGSLIRPE ATGYGNVLFA AAMLRRERGET LEGRTAVVSG
251 SGNVAIYTIQ KLAALGANAV TCS DSSGYVV DEKGIDL DLL KQVKEVERAR
301 VDTYAQR RGA SARFVPGR RV WEVPADIALP SATQNELDAD DATALI
```

DapA, dihydrodopicolinate synthase Length: 307 amino acids

```
1  MTLASSLEPT TEPLFNGLYV PLVTPFTDDL RLAPEALARL ADEALSAGAS
51  GLVALGTTAE AATLTAEERE TVIRVCSAAC RAHGAPLIVG VGTNDTATAI
101 TALRELAARG DVAAALVPAP PYIRPGEAGT LAHFAALAEH GGLPLVVYDI
151 PYRTGQTLGA GTITALGRLP EVVGIKHATG SIDPTTMELL DSPLPGFAVL
201 GGDDIVLSPL VAAGAHGGIV ASANLRTADY AEMIALWRRG SAAPARALGA
251 DLARLSAALF TEPNPTVIKG VLHAQNRIPS PAVRMPLLA SADSVRRAAP
301 LAASRK*
```

ORF3, putative transcriptional activator protein Length: 314 amino acids

```
1  MLDVRRRLHLL RELDRRG TIA AVAEALTFTA SAVSQQLGVL EREAGVPLLE
51  RSGRRVLTTP AGRSLVAHAD AVLNRLEQAV AELAGARDGI GGPLRIGTFP
101 SGGHTIVPGA LAELASRHPA LEPMVREIDS ARVSDGLRAG ELDVALVHDY
151 DFVPATPDTT VDEVPLLEEP MYLVTHAADT ATDSGSGSTL AALLGPCAEV
201 PWITARDGTT GHAMAVRACQ AAGFQPRIRH QVNDFRTVLA LVAAGQGAGF
251 VPRMAAEPSP AGVVLT KLPL FRRSKVAFRA GGGAHPAIAA FVAAATTAVE
```

01 RMAGSRGPAG GSE*

ORF4, hypothetical protein Length: 139 amino acids

1 MADDAYLFLL PDRHPRLGAA LAAVGALECT ETPAVHAWLQ AHEASVSSEQ
51 VRILPADAET LIPKDAERLP VPLSEEEALK VEQECAPQTV TDMESELLAF
101 RETTQDWQAL VHRALTAGIP AQRIARLTGL DPTEEIGRL*

ORF5, hypothetical protein Length: 208 amino acids

1 LAVAACAAVV LPIDAVVRIS AADVGVLVFF AYLLPYLAIT MTVFVSVAPE
51 QVRSWARREA RGTFLQRYVL GTAPGPGGSL FIAAAALVVA VLWLPGHLST
101 TFSALPRTL V ALALVVAWI CVVVAFAVTF QADNLVENER ALEFPGERSP
151 AWADYVYFAL AAMTTFGT TD VDVTSRDMRR TVAANTVIAF VFNTVTVAIL
201 VSALGGR*

ORF6, hypothetical protein Length: 63 amino acids

1 MTVMDKLKQM LKGHEDKAGQ GIDKAGDFVD GKTQ GKYSQ VDTAQDKLRD
51 QFGSDQQEPP QR*

ORF7, hypothetical protein Length: 185 amino acids

1 MGTAQSQEQA AAPGACAAV RFVLCGGGVG LASSFAVVAL ASWVPWALAN
51 ALVAVVSTVV ATELHARFTF GAGGRATWRQ HAQSAGSAAA AYAVTCVAME
101 VLQQLVAAPG AVLEQVVYLS ASALAGVARF VVLRLVVFAR NRSLPAAAV
151 RTARPVRRVP APVPATVAHA ASRPAGPAAL CPAA*

AcpX, acyl carrier protein (ACP) Length: 106 amino acids

1 MTSTDHTSGQ DATELEKQLA AATPEEREKL LTDTIRTQAG TLLNTTSLDD
51 SNFLENGLNS LTALELTKTL MTLTGMEIAM VAIVENPTPA QLAHHLGQEL
101 AHTTA*

KsX, ketoacyl-ACP synthase Length: 829 amino acids

1 VANEEKLVEY LKWTTAELHQ AQQQLRELKA AQHEPIAVVS MACRLPGKTR
51 TPDDLWDLVS EGRDAVTGFP DDRAWELPEE RPYAELGGFL DDAAGFDAGF
101 FDISDTEAVA TEPLQRLMLH LAWETVERGH IAPHTLRSTL TGVYVGATGH
151 DYATRLETAP DELLPYLGGG TSGSLVSGRI AYALGLEGPA ISVDTACSSS
201 LVALHLACQA LRRGECGLAL AGGGTVMSTP HTFHAFAHQK SLAQDGRCKP
251 FAAAADGMGL GEGVGLVLE RLGDARKNGH PVLAVIRGSA VNQDGAGYGL
301 AAPNGPSQQH VIRAAALADAG LTPDQIDAVE AHGTGTPIGD AIEVQALLAT
351 YGADRSPDRP LWLGSVKSNT GHTQGAAGAA ALIKMVQAFR HGTLPPPTLHV
401 DRPTPLAAWK KGAVRLLTEA VDWPRREEPR RVGISAFATS GTNAHLILEE
451 PPVDEAPVPD AARDQTSPVA PELPVAWSLS ARTPEALRAQ AKALVTHLAA
501 TDPAPSPAEV AYSLAATRSP LEHRAVLTGT DHTELLAAAR ALAAGEDHPD
551 LVRSTPGAGP KKIAWHFDGR PADGVTTGAA PGAKPGATFG ATFGAAFGGA
601 EFHSAFPLFA SAFDEARALL DTHLPTPLPT PHSELARFAV HTALARLLE
651 TGVRPHTLTG DGVGHIAAAY AAGILTDDA CRLAAAHAAA AQAAEGEQPA
701 PPDAYEPVLK QLTFQRATLT LTSTAPADTP IASADYWHHH LTSPAPTAPP
751 TPETHTLLHL GALSPEGTQT SAVSALLTAL ARLHTTGGTV DWTPLVRRTP
801 HPRTIDLPTY SFQATRYWLH DHTAHAHV*

MonCII, probable epoxyhydrolase/cyclase Length: 300 amino acids

1 VKNLRIPVSQ TVSLNVRYRP ADGPGAPGRP FLLHGMLSN ARMWDEVAAR
51 LAAAGHPAYA VDHRGHGESD TPPDGYDNAT VVTDLVAAVT ALDLSGALVA
101 GHSWGAHLAL RLAAEHPDLV AGLALIDGGW YEFDGPVMRA FWERTADVVR
151 RAQQGTTSAA DMRAYLRATH PDWSPTSIEA RLADYRVGPD GLLIPRLTST
201 QVMSIVAGLQ REAPADWYPK VTVPVRLPL IPAIPQLSDQ VRAWVAAAEA

251 ALEQVSVRWY PGSDHDLHAG APDEIAADLL LLARSCEAMP GGKAGVRPA*

MonE, S-adeonosylmethionine-dependent methyltransferase Length: 277 amino acids

1 VNKTVAPEPS DIGHYDHKV FDLMTQLGDG NLHYGYWFDG GEQQATFDEA
51 MVQMTDEMIR RLD PAPGDRV LDIGCGNGTP AMQLARARDV EVVGISVSAR
101 QVERGNRRAR EAGLADRVRF EQVDAMNLPF DDGSFDHCWA LESMLHMPDK
151 QQVLTEAHRV VKPGARMPA DMVYLNPDPS RPRTATVSDT TIYAALTDIG
201 DYPDIFRAAG WTVLELTDIT RETAKTYDGY VEWIRahrde YVDIIGVEGY
251 ELFLHNQAAL GKMPelgyIF ATAQRP*

MonT, putative monensin resistance gene (ABC-transporter) Length: 512 amino acids

1 MSADLGARRW WAVGALVLAS MVVGFDVTIL SLALPAMADD LGANNVELQW
51 FVTSYTLVFA AGMIPAGMLG DRFGRKKVLL TALVIFGIAS LACAYATSSG
101 TFIGARAVLG LGAALIMPTT LSLPVMFSD EERPKAIGAV AGAAMLAYPL
151 GPILGGYLLN HFWWGSVFLI NVPVVILAFL AVSAWLPESK AKEAKPFDIG
201 GLVFSSVGLA ALTYGVIQGG EKGWTDVTTL VPCIGGLLAL VLFVMWEKRV
251 ADPLVDLSLF RSARFTSGTM LGTVINFTMF GVLFTMPQYY QAVLGTAMG
301 SGFRLLPMVG GLLVGVTVAN KVAKALGPKT AVGIGFALLA AALFYGATTD
351 VSSGTGLAAA WTAAYGLGLG IALPTAMDAA LGALSEDSAG VGSGVNQSIR
401 TLGGSFGAAI LGSILNSGYR GKLDLDGVPE QAHGAVKDSV FGGLAVARAI
451 KSNGLADSVR SAYVHALDVV LVVSGGLGLL GVVLA VVWLP RHVGQSTAKT
501 AESEHEAADA V*

MonRII, probable repressor protein Length: 192 amino acids

1 VPGLRERKKA RTKAAIQREA VRLFREQGYT ATTIEQIAEA AEVAPSTVFR
51 YFATKQDLVF SHDYDLPFAM MVQAQSPDLT PIQAERQAIR SMLQDISEQE

101 LALQRRERFVL ILSEPELWGA SLGNIGQTMQ IMSEQVAKRA GRDPRDPAVR
151 AYTGAVFGVM LQVSMDWAND PDMDFATTLD EALHYLEDLR P*

MonAIX, thioesterase Length: 269 amino acids

1 MDRGTAARAP QIGDEFGAAT GNGVWLRRYH AAAEAPVRLV CFFPAGGSAS
51 YYFGLSGLLA PGVEVLAVQY PGRQDRHAEP CLASVAELAD GVVPHLPCDG
101 KPFALFGHSL GAIVAFEVAR RLRGPAGPGL PVHLEFVSGGL ARPYPAGRS
151 GAFGDADILA HLRAMGGTDE RFFRSPELQE LVLPALRADY RAVATYEAPG
201 PGRLDCPITA LIGDADERTS PEQAATWRER TGAAFDLRVL PGGHFYLDGC
251 QEQVAADVTE ALTAGPGV*

MonAI, polyketide synthase multienzyme MONS 1, housing loading module and extension module 1 Length: 3026 amino acids

1 MAASASASPS GPSAGPDPIA VVGMACRLPG APDPDAFWRL LSEGRSAVST
51 APPERRRADS GLHGPGGYLD RIDGFDADFF HISPRAVAM DPQQRLLLEL
101 SWEALEDAGI RPPTLARSRT GVFVGAFWDD YTDVLNLRAP GAVTRHTMTG
151 VHRASILANRI SYAYHLAGPS LTVDTAQSSS LVAVHLACES IRSGDSIDAF
201 AGGVNLICSP RTTELAAARF GGLSAAGRCH TFDARADGFV RGEggGLVVL
251 KPLAAARRDG DTVYCVIRGS AVNSDGTDTG ITLPSGQAQQ DVVRLACRRA
301 RITPDQVQYV ELHGTGTPVG DPIEAAALGA ALGQDAARAV PLAVGSAKTN
351 VGHLEAAAGI VGLLKTALSI HHRRLAPSLN FTTPNPAIPL ADLGLTVQQD
401 LADWPRPEQP LIAGVSSFGM GGTNGHVVA AAPDSVAVPE PVGVPERVEV
451 PEPVVVSEPV VVPTWPVSA HSASALRAQA GRLRTHLAH RPTPDAAVVG
501 HALATTRAPL AHRAVLLGGD TAELLGSLDA LAEGAETASI VRGEAYTEGR
551 TAFLESGQGA QRLGMGRELY AVFPVFADAL DEAFALDVH LDRPLREIVL
601 GETDSGGNVS GENVIGEGAD HQALLDQTAY TQPALFAIET SLYRLAASFG

651 LKPDYVLGHS VGEIAAAHVA GVLSLPDASA LVATRGRIMQ AVRAPGAMAA
701 WQATADEAAE QLAGHERHVT VAAVNGPDSV VVSGDRATVD ELTAAWRGRG
751 RKAHHLKVSH AFHSPHMDPI LDELRAVAAG LTFHEPVIPIV VSNVTGELVT
801 ATATGSGAGQ ADPEYWARHA REPVRFLSGV RGLCERGVTT FVELGPDAPL
851 SAMARDCFPA PADRSRPRPA AIATCRRGRD EVATFLRSLA QAYVRGADVD
901 FTRAYGATAT RRFPLPTYPF QRRHWPAAA GVGQQPETPE LPESSESSEQ
951 AGHEREEGAR AWGGPEGRLA GLSVNDQERV LLGLVTKHVA VVLGDASGT
1001 QAARTFKQLG FDSMAAAELS ERLGTETGLP LPATLTFDYP TPLAVAAHLR
1051 AELTGTPAPA GSAPATGALG AGDLGTDEDP VAIVAMSCRY PGGAGTPEDL
1101 WRLVADGADA IGDFPTDRGW DLARLFHPDP DRSGTSCTRQ GGFLYDAADF
1151 DAEFFDISPR EALAVDPQQR LLECAWEAF ERAGLDPRAL KGSPTGVFVG
1201 MTGQDYGPRL HEPSQATDGY LLTGSTPSVA SGRLSFSFGL EGPALTVDTA
1251 CSSLVTLHL AAQALRRGEC DLALAGGATV LATPGMFTEF SRQRGLAPDG
1301 RCKPFAAGAD GTGWAEGVGL VLLERLSEAR RKGHAVLAVI RGSAINQDGA
1351 SNGLTAPNGP SQQRVIRAAL AAARLTADDEV DVVEAHGTGT TLGDPIEAQA
1401 LLATYGQGRS AERPLWLGSV KSNIGHTQAA AGVAGVIKMV MAMRHDLLPA
1451 TLHVDEPSGH VDWSTGAVRL LTEPVVWPRG ERPRRAAVSS FGISGTNAHL
1501 VLEEAGQDEY VAGAADDAGP VDGAVLPWV SGRTGAALRE QARRLRELVT
1551 GGSADVSVSG VGRSLVTTRA VFEHRAVVVG RDRDTLIGGL EALAAGDASP
1601 DVVCGVAGDV GPGPVLVFPQ QGSQWVGMGA QLLGESAVFA ARIDACEQAL
1651 SPYVDWSLTE VLRGDGRELS RVDVVQPVLW AVMVSLAAVW ADHGVTAAV
1701 VGHSQGEIAA VVVAGALTLE DGAKIVALRS RALRQLSGGG AMASLGVGQE
1751 QAAELVEGHP GVGIAAVNGP SSTVISGPPE QVAAVVADAE ARELRGRVID
1801 VDYASHSPQV DAITDELTHT LSGVRPTTAP VAFYSAVTGT RIDTAGLDTD

1851 YWVTNLRRPV RFADAVTALL ADGHRVFIEA SSHPVLTGL QETFEEAGVD
1901 AVTVPTLRRE DGGRARLARS LAQAFGAGCA VRWENWFPAT GTSTVELPTY
1951 AFQRRRYWLE APTGTQDAAG LGLAAAGHPL LGAATEIADG DIRLLTGRIS
2001 RHSHPWLAQH TLFGAAVVPA SVLAEWALRA ADEAGCPRVD DLTLRTPPLV
2051 PETAGVQVQI VVG PADARDG HRDFHVIYARP DGKDASEGEG IAE GEGASEG
2101 EGASGGTDAP WTCHADGRLV AEPTGTASED SPDTVWPPPG AEPVDLGDFY
2151 ERAAATGVGY GPVFTGLRAL WRRDGELFAE AVL PQEAPET AGFGMHPALL
2201 DAALHPALLG ERPAEEDKVV LPFTLTGVTL WATGATSVRV RLTPLD DDDPD
2251 ASADGRAWRV GVS DPTGAEV LTCEALVAVA AGRRELRAAG ERVSDLYAVE
2301 WVPVPGPGPV GEGADFSGWA GLGECGERWE CVGRVERWYE DLDALGAAVE
2351 GGASVPSVVL ATAAAAPGGA GDGAADALSA VRWTGALLDQ WLADARFADA
2401 RLVVITSGAV ATGDDFLPDP AAAAVRGLVE QAQVRHPGRI LLVDTEAGAG
2451 LGVGAGVDDA LLEQAVAMAL GADEPQLALR AGRVLAPRLT APQDAAVTEA
2501 ARPLDPDGTV LITGPAGAPV ADLAEHLVRT GQCRHLLLLP GDGELEEMAE
2551 ELRGLGATVD LSTADPADPT ALAEVVAAVE GDHPLTGVIH ATGVVDAFDP
2601 GDSASDLMID SASDSFAEAW SSRAGVTAAL HTATAHLPLD LFAVLSPAGA
2651 DLGIARSAAA AGADAFSAAL ALRRHTTVTT DTTAPPRTTA PPRTTASPT
2701 TALSSSRTTG VALAYGPPTA PRPGIKGTAP GRIPVLLDAA RAHGGGSPLL
2751 GARLAARALA AESAAEGVAG LPAPLRALAV AAAAAGAPTR RTAADRKPPA
2801 DWPARLAPLS APEQLRLLID AVRTHAAAVL GRTDPEALRG DATFKQLGLD
2851 SLTAVELRNR LVEDTGLRLP TALVFRYPTP AAIAAHLRER LTSPSETTAT
2901 QRSGGQTPAA GQASSALAPG GSAAGPPAAD TVLSDLTRME NTL SVLAAQL
2951 PHTETGEITT RLEALLTRWK TTNATANDSG DGNGGDDDA ERLKAASADQ
3001 IFDFIDNELG VGHGTSRVTP TPKAG*

MonAII, polyketide synthase multienzyme MONS 2, housing extension module
2 Length: 2239 amino acids

1 MASEEQLVEY LRRVTTELHD TRRRLVQEED RRQEPVALVG MACRFPGGVA
51 SPEDLWDLVA AGKDAIEDFP TDRGWDLEAL YDPDPAAYGT SYVRHGGFVD
101 DAGSFDADFF GISPREALAM DPQQRLMLET SWELFERAGI EPVSLKGSRT
151 GVIYAGVSSSED YMSQLPRIPE GFEGHATTGS LTSVISGRVA YNYGLEGPAV
201 TVDTACSASL VAIHLASQAL RQRECDLALA GGVLVLSSPL MFTEFCRQRG
251 LAPDGRCKPF AAAADGTGFS EGIGLLLLER LSDARRNGHK VLA VIRGSAV
301 NQDGASNGLT APNDAAQEQV IRAALDNARL TPSEVDAVEA HGTGTKLGDP
351 IEAGALLATY GQHRARPLLL GSLKSNIGHT HATAGVAGVI KTVMAIRNGL
401 LPATLHVEEL SPHVDWDAGA VEVVTEPTPW PETGHPRRAG VSAFGISGTN
451 AHLILEEAPP EEDVPAPVVV ESGGVVPWVV SGRTPEALRE QARRLGEFVA
501 GDTDALPNEV GWSLATRSV FEHRAVVVGR DRDALTAGLG ALAAGEASAG
551 VVAGVAGDVG PGPVLVFPQG GAQWVGMAQ LLDESAVFAA RIAECERALS
601 AHVDWSLSAV LRGDGSELSR VEVVQPV LWA VMVSLAAVWA DYGVTPAAVI
651 GHSQGEMAAA CVAGALSLED AARIVAVRSD ALRQLQGHGD MASLSTGAEQ
701 AAELIGDRPG VVVAAVNGPS STVISGPPEH VAAVVADAEA RGLRARVIDV
751 GYASHGPQID QLHDLLTERL ADIRPTNTDV AFYSTVTAER LTDTTALDTD
801 YWVTNLRQPV RFADTIEALL ADGYRLFIEA SAHPVLGLGM EETIEQADMP
851 ATVVPTLRD HGDTTQLTRA AAHAFTAGAD VDWRRWFPAD PAPRTIDLPT
901 YAFQRRRYWL ADTVKRDSGW DPAGSGHAQL PTAVALADGG VVLNGRVSAE
951 RGGWLGGHV V AGTVLVPGAA LVEWVLRAGD EAGCPSLEEL TLQAPLVLP E
1001 SGGLQVQVVV GAADEQGGRR DVHVYSRSEQ DASAVWQCHA VGELGRASVA
1051 RPVRQAGQWP PAGAEPVEVG GFYEGVAAAG YEYGPAFRGL RAMWRHGDDL

1101 LAEVELPEEA GSPAGFGIHP ALLDAALHPL LAQRSRDGAG AGAHGGQVLL
 1151 PFSWSGVSLW ASEATTVRVR LTGLGGGDDE TVSLTVTDPA GGPVVDVAEL
 1201 RLRST\$ARQV RGSAGPGADG LYELRWTPLP EPLPVPAPAN GRDVAADLSG
 1251 CAVLGELVAE PGPIDLEGC PCYPGVGALA DNASPPSMIL APVHSDTTGG
 1301 DGLALTERVL RVIQDFLAAP SLEQKQTRLA FVTRGAADTG STTGGSAAAPA
 1351 EAVDPAVAHV WGLVRSQAQSE NPGRFVLLDT DAPLDQASVA PLVDAVRSVA
 1401 EADEPQVALR GGRLLVPRWA RAGEPVELAG PAGARAWRLV GGDSGTLEAV
 1451 VAEACDDIVL RPLAPGQVRV AVHTAGVNFR DVLIALGMYP DPDALPGTEA
 1501 AGVVTEVGPV VTRL\$VGDRV MGMMDGAFGP WAVADARMLA PVPPGWGTRQ
 1551 AAAAPAAFLT AWYGLVELAG LKAGERVLIH AATGGVGMAA VQIARHVGAE
 1601 VFATASPGKH AVLEEMGIDA AHRASSRDLA FEDAFRQATD GRGVDVVLNS
 1651 LTGELLDASL RLLGDGGRFV EMGKSDPRDP ELVALEHPGV SYEAFDLVAD
 1701 AGPERLGLML DRLGELFAGG SLVPLPVTAW PLGRAREALR HMSQARHTGK
 1751 LVLDVPAPLD PDGTVLVTGG TGTIGA\$VAE HLARTGESKH LLIVSRSGPA
 1801 AHGAEELVSR IAEFGAEATF VAADVSEPDA VAALIEGIDP AHPLTGVVHA
 1851 AGVLDNALIG SQTTESLTRV WAAKAAAAQQ LHEATRESRL GLFVMFSSFA
 1901 STMGTPGQAN YSAANAYCDA LAALRR\$EGL AGL\$VAWGLW EAT\$GLTGTL
 1951 SAADRARIDR YGIRPTSAAR GCALLAAARA HGRPDLLAMD LDARVPAASD
 2001 APVPAVLRTL AAAGAPATAR PTAAAAADGA TDWSGRLAGL TEEARLELLT
 2051 ELVCTHAAGV LGHADAGAVQ VDAPFKELGF DSLTAVELRN RIAAATGLKL
 2101 PAALVFDYPQ ARVLA\$HLAE RLVPEGAGAM GGVSGAEGVR DAYGAGGPGG
 2151 DMTAQVLLEV ARVEHTLSAA VPHGLDRAAV AARLEALLAR CTATTAATGA
 2201 AGAAVEGDGD SDGDGAVDQL ETATAEQVLD FIDNELGV*

MonAIII, polyketide synthase multienzyme MONS 3, housing extension modules 3 and 4 Length: 4133 amino acids

1 MVSEEKLV DY LKRVSADLHA TRQRLREAEE RGQEPVAVVE AACRYPGGIR
51 TPEDLWDLVA AGGNALGAFF DNRGWDLRRL FHPDPDHPGT TYAREGGFLH
101 DADLFDPEFF GISPREAAVL DPQQRLLEC AWEALERAGI DPRSLQGSRT
151 GUYAGAALPG FGTPHIDPAA EGHLVTGSAP SVLSGRLAYT FGLEGPAVTI
201 DTACSSSLVA VHLLAAHALRQ RECDLALAGG VTMTPPYVF TEFSRQGLA
251 ADGRCKPFAA AADGTAFSEG AGLLVLERLS DARRAGHRVL AVIRGSAVNQ
301 DGASNGLTAP NGPAQQRVIR AALAGARLSP AEVDAVEAHG TGTRLGDPPIE
351 ADALLATYGO ERHGGRPLWL GSVKSNIGHT QGAAGAAGLI KMVQALRHET
401 LPATLYADEP TPHADWESGA VRLLSAPVAW PRGEHGEHTR RAGISSFGIS
451 GTNAHLILEE APAADAEGAG GDGDGDGGGV RPVVVRVGATG PREEQGGQGG
501 QEQHQQQRQQ RQRSSMMPTP HLPWLLSARS PAALRAQADA LANHVAHADH
551 SIADIGGTLL RRTLFEHRAV VLGTDRDERA AALAALAAGR AHPALTRAAG
601 PARNGGTAFI FTGQGSQRPG MGRQLYDTFD VFAESLDETC ARLDPLLEQP
651 LKPVLFAPAD TAQAAVLHGT GMTQAALFAL EVALYRQVTS FGIAPSHLTG
701 HSVGEIAAAH VAGVFSLADA CTLVAARGRL MQALPAGGAM LAVQAAEDDV
751 LPLLAGQEER LSLAAVNGPT AVVVSGEAAA VGEVEKALRG RGLKTKRLNV
801 SHAFHSPLIE PMLDDFREVA RGLTFHAPTL PVVSNLTGRL ADAELMADAE
851 YWVRHVRRPV RFHDGLRALS EQGVVRYLEL GPDPVLATMV QDGLPAPAEG
901 EEPEPVVAAA LRSKHDEGRT LLGAVAALHT DGQPADLTAL FPADAGQVPL
951 PTYRFQRRRY WRVAPDAAAP ARAAGLQETG HPLLPAVIRQ ADGGILLAGR
1001 LSLRTHPWLA DHTIAGGVPL PATAFVELAL LAGRHAACDT IDDLTLETPL
1051 LLDDTGTGVG AAVGAGADAL VDAIEVQLAL GAPDGSGRRA LTVHSRPADD
1101 AADDGDAADA ADAAGRGGPG GSGDLGDPGD PGDLGDGGGS RGWRRHATGI

1151 LSAGPAAEPA APDAAPWPPA DATA LDVDAL YARLDAQGYS YGPAFRAVHA
1201 AWRHGDDLYA DVRLADEQRA EADAFALHPA LLDAALHAVD ELYRGSEGRG
1251 QEQGQGGQEP EQGRGDADAP VRLPFSFS DI RHHATGATRL WVRLSPQGDD
1301 RLRLSLTDGE GGQVATVDAL QLRLIPADRW RAARPTTAAP LYHLDWHELP
1351 LPEPAETDPA AHSWAVLG AH DAGLAPAAHY PDLAALKAAV EAGEPVPDIV
1401 FAPFPAQGTE TDVPAQVRAH ARHALELLRD WLTTEAFAAA RLVVLT TGAV
1451 TARPEDGPAD LATAPVWGLV RAAQAEQPDH VVLVDIDKDI DKDTDEETDQ
1501 ATDAGTASRH ALPAALAAAA AQAETQLALR AGTVLVPRLA VVPPRTDTPA
1551 LHATAPESTT DTV DSTGIAG AAESGGTVLI TGGTGGLGQA VARHLAAAHG
1601 ARHLLLVSRR GDAAEGVAEL RADLADDGVD VRVAACDITD RDALAGLLAD
1651 IPA AHPLTAV VHTAGVIDDS LITAMTPERL DAVLAPKADA AWHLHELTRD
1701 KDLSAFVLFS SGASVLGNGG QANYAAANTF LNTLAEHRRA AGLAATSVAV
1751 GLWESASGGM AARLG DADRA RIHRTGVTGL TDEQALALFD AALTAEHPTV
1801 LATRF DRAVL RGQAAARTLQ PALRGLVRTP RPTASAGAIG STAATGSATD
1851 ENAPSSWAAR LARLSAADRD RALNELIREQ IATVLAHPSP DTIELGRAFQ
1901 ELGFDSL TAL ELRNRLSTAT GIRLPATLVF DHPSPTALVR HLHSHLPDEA
1951 QHTSPTAPGA SAEGTAATAT GIDDDPIAIV GMACRYPGGV TSPEQLWQLV
2001 ATGTDAIGPF PEDRGWD TAG LFD PDPDQVG HSYTREGGFL YDAARFDAGF
2051 FGISP REAAA TDPQQRLLLE TAWQAFEHAG IDPAALRGTP CGVITGIMYD
2101 DYGSRFLARK PDGFEGRIMT GSTPSVASGR VAYTFGLEGP AITVDTACSS
2151 SLVAMHLAAQ ALRQGECELA LAGGV TVMAT PNTFVEFSRQ RGLAPDGRCK
2201 PFAAAADGTG WGE GAGLVVL ERLSDARRKG HRVLALLRGS AVNQDGASNG
2251 MTAPNGPSQE RVIR TALAGA GRGPEDIDVV EAHGTGTTLG DPIEAQALLA
2301 TYGQGRPEDR PLWLGSVKSN IGHTQAAAGV AGVIKMVMAL RHEQLPTTLH

351 ADEPTPHVQW DGGGVRLLTE PVPWSRGERT RRAGVSSFGI SGTNAHLILE
2401 EPPEEDLPEP VAAEPGGVVP WVVSGRTPDA LREQARRLGE FVVGAGDVSA
2451 AEVGWSLATT RSVFEHRVAV AGRDRDDLVA GMQALAAGET PTDVVSGAAA
2501 SSGAGPVLVF PGQGSQWVGM GAQLLDESPV FAARIAECEQ ALSAYVDWSL
2551 SDVLRGDGSE LSRVEVVQPV LWAVMVSLAA VWADYGVTTPA AVVGHSQGEM
2601 AAACVAGALS LEDAARIVAV RSDALRQLQG HGDMA SLGTG AEQAAELIGD
2651 RPGVVVA AVN GPSSTVISGP PEHVAAVVAE AEARGLRARV IDVGYASHGP
2701 QIDQLHDLLT EGLADIRPAN TDVAFYSTVT AERLTDTTAL DTDYWVTNLR
2751 QPVRFADTIE ALLADGYRLF IEASAHPVLG LGMEETIEQA DIPATVVPTL
2801 RRDHGD TTQL TRAAAHAF TA GADVDWRRWF PADPTPRTVD LPTYAFQHQH
2851 YWLEEPSGLT GDAADLGMVA AGHPLLGACV ELAESDSYLF TGRLSRRAPS
2901 WLAEHVVAGT VLVPGAALVE WVL RAGDEAG CPTIEELTLQ APLVLPESGG
2951 LQVQVVVGAT DEQSGRRDVH VYSRSEQDAS AVWVCHAVGV VSSEMPEAAA
3001 ELSGQWPPAG AEAVDVEDFY ARAAEAGYAY GPAFQGLRAL WRHGTELF AE
3051 VVLPEQAGGH DGFGIHPALL DAALHPLMLL DRPADGQMWL PFAWSGVSLN
3101 ADRATHVRVR LSPRGEAAER DLRVVIADAT GAPVLTVDAL TLRAADPGRL
3151 GAAARGGVDG LYTVDWTPLP LPQPLPLPRT DAGGSADWVI LSDNSSAALA
201 DAVSSATAAG GGAPWALLAP VGGGSADDGL PVVRRTLSLV QEFLAAPELT
3251 ESRLVIVTRG AVATDADGDV AASAAAVWGL IRSAQSENP G RFVLLDVEEE
3301 HLHPDGGELP YAALRHAVEE LDEPQLALRS GKFLVPRMTP AAAPEELVPP
3351 VGTSGWRLGT SGTATLENLS VIDAPEAFAP LEPGQVRISV RAAGMNFRDV
3401 LIALGMYPDK GTFAGSEGAG HVTEVGPGVT HLSVGDRVMG LFEGAFAPLA
3451 VADARMVVPI PEGWSFQEAA AVPVVFLTAW YGLVDLGRLR AGESLLIHAG
3501 TGGVGMAATQ IARHLGAEVF ATASPAKHGV LDGMGIDA AH RASSRDLDFE

3551 ETLRAATGGR GMDVVLNSLA GEFTDASLRL LAEGGRMVDM GKTDKRDPR
 3601 VAAEHAGAWY RAFDLVPHAG PDRIGEMLAE LGELFASGAL APLPVQTWPL
 3651 GRAREAFRFM SQAKHTGKLV LEIPPALDPD GTVLITGGTG VLAAVAEHL
 3701 VREWGVRHLL LAGRRGSEAP GSSELAEELT ELGAEVTFAA ADVSDPDAVA
 3751 ELVGKTDPAH PLTGVIHAAG VLDDAVVTAQ TPESLARVWA AKATAAHLH
 3801 EATREARLGL FLVFSSAAAT LGSPGQANYA AANAYCDALV RQRAEGLAG
 3851 LSIGWGLWQT ASGMTGHLGE TDLARMKRTG FTPLTTEGGL ALLDAARAHG
 3901 RPHVVAVDLD ARAVAAQPAP SRPALLRALA AGATPGARTA RRTAAAGSVA
 3951 PAGGLADRLA GLPHPERRRL LLDLVRGNVA GVLGHSDDHA VRPDTSFKEL
 4001 GFDSLTADEL RNRLAAATGL KLPAALVFDY PESATLVDHL LERLSPDGAP
 4051 PPVKDAADPV LNDLGRIESS LDALALDADA RSRVTRRLNT LLSKLNGAAT
 4101 AGSPADVTDL DALDALDDVS DDEMFEFIDR EL*

MonAIV, polyketide synthase multienzyme MONS 4, housing extension modules 5 and 6 Length: 4039 amino acids

1 MSSAEESSPD VSGTGVSGTG ESATGTSSTE AKLRQYLKRV TVDLGQARRR
 51 LREVEERAQE PIAIVSMACR FPGDTRTPEA LWDLVAEGGD AIDDFPTNRG
 101 WDLESLYHPD PDHPGTSYVR RGGFLYDAPA FDASFFGISP REALAMDPQQ
 151 RVLMETAWQL LERAGIDPAS LKLSATGVYI GAGVLGFGGA QPDKTVEGHL
 201 LTGSALSVLS GRISFTLGLE GPSVSVDTAC SSSLVSMHLA AQALRQGECD
 251 LALAGGVTVM STPGAFTEFS RQGALSPDGR SKAFAASADG TGFSEGAGLL
 301 LLERLSDARR NGHKVLAIR GSAVNQDGAS NGLTAPNGPS QERVIRAALA
 351 NAGLGAAEVD AVEAHGTGTK LGDPIEAGAL LATYGRDRDE DRPLWLGSVK
 401 SNIGHPOGAA GVAGVIKVM ALQRELLPAT LYVDEPTPHV DWSSGSVRLI
 451 TEPVPWTRGE RPRRAGVSAF GMSGTNAHVI LEEAPPEEAA AAETPAEGTG
 501 AVVPWVSGR GEEALRAQAA QLAEHVRDDD QRPASPLEVG WSLATTRSVF

551 ENRAVVVGDD RDALLDGLRS LAAGEASPDV VSGAVGPTGP GPVMVFPGQG
601 GQWVGMGARL LDESPVFAAR IAECEQALSA YVDWSLTDVL RGDGSELARI
651 DVVQPV LWAV MVALAAVWAD QGIEPAAVVG HSQGEIAAAC VVGAISLDEA
701 ARIVAVRSVL LRQLSGRGGM ASLGMGQEQA ADLIDGHPGV VVAAVNGPSS
751 TVISGPPEGI AAVVADAQER GLRARAVASD VAGHGPQLDA ILDQLTEGLA
801 GIRPAATDVA FYSTVTAGHL TDTTELDTAY WVRNVRRTVR FADTIDALLA
851 DGYRLFIEVS PHPVLNLALE GLIERAAVPA TVVPTLRRDH GDTTQLARAA
901 AHAFAGADV DWRRWFPA DP APRTVDLPTY AFQRQDFWPA PAGGRSGDPA
951 GLGLAASGHP LLGASVGLAS GDVHLLSGRV SRQSAAWLDD HVVAGQALVP
1001 GAAQVEWVLR AGDDAGCSAL EELTLQTPLV LPDTGGLRIQ VVVEAADAHG
1051 RRDVRLFSRP DDDDAFASTH PWTCHATGVL APAPTDGTNG TRDAADTLDG
1101 AWPPADAEPV PADDLYAQAD RTGYGYGPAF RGVRLWRHG KDVLAEVTLP
1151 KEAGDPDGFG IHPALLDAVL QPAALLLPPT DAEQVWLPFA WNDVALHAVR
1201 ATTVRVRLTP LGERIDQGLR ITVADAVGAP VLTVRDLRSR PTDTGRLAAA
1251 ATRDRHGLFD LEWIAPENAA ENAAGPARDA SEGWVTLGED AASLADLLAS
1301 VEAGAPAPQL VAAPVEPDRT DDGLALATHV LDLVQTWLAS PLHDSRLVLV
1351 TRGAVTDADV DVAAA VWGL VRS AQSEHPG RFTLIDLGP DTLAAAMQAA
1401 HLEEPQLAVH GGEIRVPRLV RATTDPTAPN GTPEADRTAD PSEGLHRNGT
1451 VLITGGTGVL GRLVAEHLVT EWGVRHLLLA SRRGDQAPGS AELRARLSEL
1501 GASVEIAPAD VGDAEAVAAL IASVDP AHPL TGVIHAAGVL DDAVITAQTP
1551 ESLARVWATK ATAARHLHEA TRETPLDEFFV VFSSAAASLG SPGQANYAAA
1601 NAYCDALVQH RRAQGLAGLS IAWGLWQATS GMTGQLSETD LARMKRTGFA
1651 ALTDEGGLAL LDAARAH DRA YVVAADLDPR AVTDGLSPLL RALTAPATRR
1701 RVASEGLADG ALATRLAGLD ADGRLRL LTD VVREYVA AVL GHGSAARVGV

1751 DIAFKDLGFD SLTAVELRNR LSAACDVRLP ATLIFDHPTP QALATHLVDR
1801 LAGSTSATTT VNATAPAAAH VAAGADVDDAD TDDPVAIVAM TCRFPGGVAS
1851 PDDLWDL LDA RKDAMGAFPT DRGWDLERLF HPDPDHPGTS YTDQGGFLPD
1901 AGDFDAAFFG INPREALAMD PQQRLLLEAS WEVLERAGID PTTLKGTPTG
1951 TYVGLMYHDY AKSFPTADAQ LEGYSYLAST GSMVSGRVAY TLGLEGPAVT
2001 VDTACSSSLV SIHLATQALR HGECDLALAG GVTVMADPDM FAGFSRQRGL
2051 SPDGRCKAYA AAADGVGFSE GVGVLLLERL SDARRHGRRV LGVVRGSAVN
2101 QDGASNGLTA PNGPSQERVI RQALASGGLS SVDVDVVEGH GTGTTLGDP
2151 EAQALLATYG QGRPEDRPLW LGSVKSNIH TQAAAGVAGV IKMVMAMRHG
2201 VVPASLHVDV PSPHVEWDSG AVRLAVESVP WPQVEGRPRR AGVSSFGASG
2251 TNAHVIVESV PDGLEEDSVS VGGEALETET DGRLVPWVVS ARSPQALRDQ
2301 ALRLRDFASD ASFRAPLADV GWSLLKTRAL HEHRAVVVGA ERAELIAALE
2351 ALATGEPHAA LVGPACSQAR VGGDDVWVLF SGQGSQLVGM GAGLYERFPV
2401 FAAAFDEVCG LLEGPLGVEA GGLREVVRG PRERLDHTVW AQAGLFALQV
2451 GLARLWESVG VRPDVVLGHS IGEIAAAHVA GVFDLADACR VVGARARLMG
2501 GLPEGGAMCA VQATPAELAA DVDGSAVSVA AVNTPDSTVI SGPSDEVTRI
2551 AGVWRERGRK TKALSVSHAF HSALMEPMLA EFTEAIRGVK FRQPSIPLMS
2601 NVSGERAGEE ITDPEYWARH VRNAVLFQPA IAQVADSAGV FVELGPAPVL
2651 TTAAQHTLDE SDSQESVLVA SLAGERPEES AFVEAMARLH TAGVAVDWSV
2701 LFAGDRVPGL VELPTYAFQR ERFWLSGRSG GGDAATLGLV AAGHPLLGA
2751 VEFADRGGCL LTGRLSRSGV SWLADHVVAG AVLVPGAALV EWALRAGDEV
2801 GCVTVEELML QAPLVVPEAS GLRVQVVVEE AGEDGRRGVQ IYSRPDADAV
2851 GGDDSWICHA TGVLSPEAS LDTELGGVWP PAGAEPLDVD GFYAQAGEAG
2901 YGYGPAFRGL RAVWRHGQDL LAEVLPEAA GAHDGYGIHP ALLDATLHPL

2951 LAARFMDGSE DDQLYVPFGW AGVSLRAVGA TTVRVRLRPV GESVDQGLSV
 3001 TVTDATGGPV LSVDSLQTRP VKPSQLAAQ QPDVRGLFTV EWTPLPQTDA
 3051 DGEADWVVL S DGVGRLADV SAAGGEAPWA VVAPVDASVG DGREGLDGRL
 3101 VVERVLSLVQ EFLALPELAE SRLLVVTRGA VATGVDGDGD VDASAAAVWG
 3151 LVRSQAQSEN GRFILLDVDG DGDDQGPDLN GRHLPBATLR HAAEELDEPQ
 3201 LALREGTLYV PRLTQARQSA ELVVPPGEPA WRLRMVHDGS LDALAAVACP
 3251 EALEPLAPGQ VRIAVHAAGI NFRDVLVALG MVPAYGAMGG EGAGVVTEVG
 3301 PEVTHVSVGD RVMGVFEGAF GPVVIAEARM VTPVPQGWD M REAAGIPAAF
 3351 LTAWYGLVEL AGLKAGERVL VHAATGGVGM AAVQIARHVG AEFATASPG
 3401 KHAVLEEMGI DAAHRASSRD LAFEGTFREA TGGRGMDVVL NSLAGEFIDA
 3451 SLRLLGDGGR FLEMGKT DVR AAEEVAAEHA DVSYTAYDLV GDAGPDRISN
 3501 MLDKLVLEFA SERLKPLPVR SWPLDKAQEA FRFMSQAKHT GKLVL EIPPA
 3551 LDPEGTVLVT GGTGALGQVV AEHLVREWGV RHLLLASRRG PEAPGSDELA
 3601 SKLTGLGAEV TIVAADVSDP ASVVELVGKT DPSHPLTG VV HAAGVLEDGV
 3651 VTAQTPEGLA RVWAAKAAAA ANLHEATREM RLGLFVVFSS AAATLGSPGQ
 3701 ANYAAANAYC DALMQHRRAV GQVGLSVGWG LWEAPDAKPG VAADAKASAA
 3751 TVGKASALSD GTNGSAPQDT TGTAPQGMTG GLTDTDVARM ARIGVKGMSN
 3801 AHGLALFDAA HRHGRPHLVG FNLDLRTLAT HPLHTRPALL RGLATPTAGG
 3851 ASRPTATAGG QPADLAGRLA ALSPSDRHHT LVRLIREQAA TVLGHHPDSL
 3901 TTGSTFKELG FDSLTAVELR NRLSAATGLR LPAGLVFDHP DADILAEHLG
 3951 AQLAPDGDTP AGAEATDPVL RDLAKLENAL SSTLVEHLDA DAVTARLEAL
 4001 LSNWKAASAA PGSGSTKEQL QVATTDQVLD FIDKELGV*

**MonAV, polyketide synthase multienzyme MONS 5, housing extension
 modules 7 and 8 Length: 4107 amino acids**

1 MASEEELVDY LKRVAELHD TRQRLREVED RRQEPVAVVG MACRFPGGIE
51 TPEGLWELVA AGDDAIEPFP TDRGWDLEGI YHPDPDHPGT CYVREGGFLA
101 APDRFDSDFE GFSPREALAS SPQLRLLET SWEALERAGI NPASLKGSPT
151 GVVYGAATTG NQTQGDPPGK ATEGYAGTAP SVLSGRLSFT LGLEGPVTV
201 ETACSSSLVA MHLAANALRQ GECDLALAGG VTMSTPEVF TGFSRQRGLA
251 PDGRCKPFAA AADGTGWGEG AGLILLERLS DARRKGHKVL AVIRGSAINQ
301 DGASNGFTAP NGPSQRRVIR QALSSAHLST SEIDVVEAHG TGTRLGDPIE
351 AEALIATYGK EREDDRPLWL GSVKSNIGHT QAAAGVAGVI KVMALQREL
401 LPATLNVDEP TPHVQWEGGG VRLLETPVPW SRGERPRRAG ISSFGISGTN
451 AHVVLEEAPP EEDVPGPVAA EPEGVVPWV SARTEEALSE QARRLGEFVA
501 DTDPSADV WSLTTSRAIL EHRAVVVGRD RDALTAGLAA LAAGEESADV
551 VAGVAGDVGP GPVLVFPQG SQWVGMAQL LDESPVFAAR IAECEQALSA
601 YVDWSLSAVL RGDGSELSRV EVVQPVLWAV MVSLAAVWAD YGVTPAAVIG
651 HSQGEMAAAC VAGALSLEDA ARVVAVRSDA LRQLMGQGM ASLGASSEQA
701 AELIGDRPGV CIAAVNGPSS TVISGPPEHV AAVVADAEER GLRARVIDVG
751 YASHGPQIDQ LHDLLTDRLA DIRPATTDVA FYSTVTAERL TDTTALDIDY
801 WVTNLRQPVR FADTIDALLA DGYRLFIEAS AHPVLGLGME ETIEQADIPA
851 TVVPTLRRDH GDTTQLTRAA AHAFATAGTV DWRRWFADP TPRTIDLPTY
901 AFQRRSYWLP VDGVDVRSR GLRRVEHSLP PAALGLADGA LVLTGRLAAS
951 GGGGGWLADH AVAGTTLVPG AALVEWALRA ADEAGCPSLE ELTLQAPLVL
1001 PGSGGLQVQV VVGPDAGQGG RREVRVFSRV DSDDEAAGQD EGWSCHATGV
1051 LSPEPGAVPD GLSGQWPPTG AEPLISDLY EQAASAGYEY GPSFRGLRSV
1101 WRHGHNLLAE VELPEQAGAH DDFGIHPVLL DAALHPALLL DQNAPGEEQE
1151 PAQPALRLPF VWNGVSLWAT GAATVRVRLA PHGGGETDDS AGLRVTVADA

201 TGAPVLSVDS LALRPADPEL LRTAGRAGSG TNGLEFTVEWT ALPPADVADH
1251 AAGDGWAVLG QDVPDWAGAD MPRHPDMASL SAALDEGTQA PAAVFEVETTA
1301 TSHATPNTAA DVTLDASGRA VAERTLHLLR DWLAEPRLA ETRLVLITHHA
1351 VTTPADDDVN AAPLDVPAAA LWGLIRSAQA EHPDRFVLLD TDAKANTDPG
1401 PDTSTDHSTA SGTYRTVIAR ALATGEPQLA VRAGELLAPR LARAATPTPE
1451 TPTPETQPD T GSGSEAGAGS GSGPGATLDP DGTVLIAGGT GMMGGLVAEH
1501 LVRAWSVRHL LLVSRQGPDA PDARDLADRL VGLGATVRIV AADLTDGRAT
1551 ADLVASVDPA HPLTGVIHAA GVLD DAVVTA QTS DQLARVW AAKASVAANL
1601 DAATSELPLG LFLMFSSAAG VLG NAGQAGY AAANAFVDAL VGRRRATGLP
1651 GLSIAWGLWA RGSAMTRHLD DADLARLRAG GVKPLLDEQG LALLDAARAT
1701 AAHTSLVVAA GIDVRGLNRD DVPAILRDLA GRTRRRAAAD STVDQAALER
1751 RLTGLDEAER RAVVTDVVRE CVA AVLGHRS AADV RTEANF KDLGFDSLTA
1801 VQLRNRLSAA SGLRLPATLA FDHPTPQALA AYLGTRL SGR TATPVAPVAP
1851 SAAATDEPVA IVAMACKYPG GATSPEGLWD LVAEGVDAVG AFPTGRGWDL
1901 ERLFHPDPDH PGTSYADEGA FLPDAGDFDA AFFGINPREA LAMPDQQRLL
1951 LEASWEVLER AGIDPTTLKG TPTGTYVGVM YHDYAAGLAQ DAQLEGYSML
2001 AGSGSVVSGR VAYTLGLEGP AVTVDTACSS SLVSIHLAAQ ALRQGECTLA
051 LAGGVTVMAT PEVFTGFSRQ RGLAPDGRCK PFAAAADGTG WGEGVGVLLL
2101 ERLSDARRHG RRVLG VVRGS AVNQDGASNG LTAPNGPSQE RVIRQALASG
2151 GLSSVDVDVV EGHGTGTTLG DPIEAQALLA TYGQGRP VDR PLWLGSVKSN
2201 IGH TQAAAGV AGVIKMVMAM RHGVVPASLH VDVPSPHVEW DSGAVRLAVE
2251 SVPWPEVEGR PRRAGVSSFG ASGTNAHVIV ESVPDGLGED SVSVSGEAPE
2301 TETDGR LVPW VVSARSPQAL RDQALRLRDA VAADSTVSVQ DVGWSLLKTR
2351 ALFEQRAVVV GRERAELLSG LAVLAAGEEH PAVTRSREDG VAASGAVVWL

2401 FSGQGSQLVG MGAGLYERFP VFAAAFDEVC GLLEGPLGVE AGGLREVVFR
2451 GPRERLDHTM WAQAGLFALQ VGLARLWESV GVRPDVVLGH SIGEIAAAHV
2501 AGVFDLADAC RVVGARARLM GGLPEGGAMC AVQATPAELA ADVDDSGVSV
2551 AAVNTPDSTV ISGPSGEVDR IAGVWRERGR KTKALSVSHA FHSALMEPML
2601 AEFTEAIREV KFTRPKVSLI SNVSGLEAGE EIASPEYWAR HVRQTVLFPQ
2651 GIAQVASTAG VFVELGPGPV LTAAQHTLD DVTDRHGPEP VLVSSLAGER
2701 PEESAFVEAM ARLHTAGVAV DWSVLFAGDR VPGLVELPTY AFQRERFWLS
2751 GRSGGGDAAT LGLVAAGHPL LGAAVEFADR GGCLLTGRLS RSGVSWLADH
2801 VVAGAVLVPG AALVEWALRA GDEVGCVTVE ELMLQAPLVV PEASGLRVQV
2851 VVEEAGEDGR RGVQIYSRPD ADAVSGDDSW ICHATGTLTP QHTDAPNDGL
2901 AGAWPAAGAV PVDLAGFYER VADAGYAYGP GFQGLRAVWR HGQDLLAEVV
2951 LPEAAGAHDG YGIHPALLDA TLHPALLLDW PGEVQDDDGK VWLPFTWNQV
3001 SLRAAGAATV RVRLSPGEHD EAEREVQVLV ADATGTDVLS VGSVTLRPAD
3051 IRQLQAVPGH DDGLFSVDWT PLPLSRTDVS QTDADGDADW VVLSDGVGSL
3101 ADVVSAAGGE APWAVVAPVG ASAGGGLAGF DRREGLDGRL VVERVLSLVQ
3151 EFLAAPELAE SRLLVLTRGA VATGGDGDGD VDASAAAVWG LVRSQAQSEN
3201 GRFILLDVDM DVDVDVDMDV DVDVDVDVDV DGDGNGSDLD PDLNGRRLPH
3251 ATLRHAAEEL DEPQLALRDG QLLVPRLVRA TGGGLVVAPT DRAWRLDKGS
3301 AETLESVAPV AYPGVMEPLG PGQVRLGIHA AGINFRDVLV SLGMVPGQVG
3351 LGGEGAGVVT ETGPDVTHLS VGDRVMGVLH GSFGPTAVAD TRMVAPVPQG
3401 WDMRQAAAMP VAYLTAWYGL VELAGLKAGE RVLIHAATGG VGMAAVQIAR
3451 HLGAEVFATA SAAKHVVLEE MGIDAHRAS SRDLAFEDTF RQATDGRGMD
3501 VVLNSLTGEF IDASLRLLDG GGRFLEMGT DVRTPEEVAA EYPGVITYTVY
3551 DLVTDAGPDR IAVMMSELGE RFASGALDPL PVRSWPLDKA REAFRFMSQA

3601 KHTGKLVLDV PAPLDPDGTV LITGGTGALG QVVAEHLVRE WGVRLHLLAS
3651 RRGLDAPGSG ELADRLSDLG AEVTVAAADV SDPASVVELV GKTDPSHPLT
3701 GVVHAAGVLE DGIVTAQTPE GLARVWAAKA AAAANLHEAT REMRLGLFVV
3751 FSSAAATLGS PGQANYAAAN AYCDALMQRR RAAGQVGLSV GWGLWEAPDA
3801 KPGVAADAKP DVAADAKTGV AADGTPQGMT GTLSGTDVAR MARIGVKAMT
3851 SAHGLALLDA AHRHGRPHLV AVDL DTRVLA HKPAPALPAL LRAFAGDQGG
3901 QGGGRGGGRG GGPARPAAAT TRQNVDWAAK LSVLTAEEQH RTLLDLVRTH
3951 AA AVLGHAGT DAVRADAAFQ DLGFDSLTA V ELRNRLSAST GLRLPATFIF
4001 RHPTPSAIAD ELRAQLAPAG ADPAAPLFGE LDKLETVITG HAHDESTRTR
4051 LAARLQNLLW RLDDTSARSD HAAGASDADG DAVENRDLES ASDDELFEI
4101 DRELPS*

**MonAVI, polyketide synthase multienzyme MONS 6, housing extension
module 9 Length: 1701 amino acids**

1 MPGTNDMPGT EDKLRHYLKR VTADLGQTRQ RLRDVEERQR EPIAIVAMAC
51 RYPGGVASPE QLWDLVASRG DAIEEFPADR GWDVAGLYHP DPDHPGTTYV
101 REAGFLRDAA RFDADFFGIN PREALAADPQ QRVLLEVSWE LFERAGIDPA
151 TLKDTLTGVY AGVSSQDHMS GSRVPPEVEG YATTGTLSSV ISGRIAYTFG
201 LEGPAVTLDT ACSASLVAIH LACQALRQGD CGLAVAGGVT VLSTPTAFVE
251 FSRQRGLAPD GRCKPFAEAA DGTGFSEGVG LILLERLSDA RRNGHQVLGV
301 VRGSAVNQDG ASNGLTAPND VAQERVIRQA LTNARVTPDA VDAVEAHGTG
351 TTLGDPIEGN ALLATYGKDR PADRPLWLGS VKSNIGHTQA AAGVAGVIKM
401 VMAMRHGELP ASLHIDRPTP HVDWEGGGVR LLTDPVPWPR ADRPRRAGVS
451 SFGISGTNAH LIVEQAPAPP DTADDAPEGA ATPGASDGLV VPWVVSARSP
501 QALRDQALRL RDFAGDASRA PLTDVGWSSL RSRALFEQRA VVAGRERAEL
551 LAGLAALAAG EEHPAVTRSR EEAAVAASGD VVWLFSGQGS QLVGMGAGLY

601 ERFPVFAAAF DEVCGLLEGE LGVSGGLRE VVFWGPRERL DHTVWAQAGL
651 FALQVGLARL WESVGVRPDV VLGH SIGEIA AAHVAGVFDL ADACRVVGAR
701 ARLMGGLPEG GAMCAVQATP AELAADV DGS SVSVA AVNTP DSTVISGPSG
751 EVDRIAGVWR ERGRKTKALS VSHAFHSALM EPMLGEFTEA IRGVKFRQPS
801 IPLMSNVSGE RAGEEITSPE YWARHVRQTV LFQPGVAQVA AEARAFVELG
851 PGPVLTAAQ HTLDHITEPE GPEPVVTASL HPDRPDDVAF AHAMADLHVA
901 GISVDWSAYF PDDPAPRTVD LPTYAFQGRR FWLADIAAPE AVSSTDGEEA
951 GFWAAVEGAD FQALCDTLHL KDDEHRAALE TVFPALSAWR RERRERSIVD
1001 AWRYRVDWRR VELPTVPGA GTGPDADTGL GAWLIVAPTH GSGTWPQACA
1051 RALEEAGAPV RIVEAGPHAD RADMADLVQA WRASCADDTT QLGGVLSLLA
1101 LAEAPATSSD TTSHTSTSCG TGSLASHGLT GTLTLLHGLL DAGVEAPLWC
1151 ATRGAVSCGD ADPLVSPSQA PVWGLGRVAA LEHPELWGGL VDLPADPESL
1201 DASALYAVLR GDGGEDQVAL RRGAVLGRRL VPDATPDVAP GSSPDVSGGA
1251 AHADATSGEW QPHGAVLVTG GVGHLADQVV RWLAASGAEH VVLLDTGPAN
1301 SRGPGRNDDL AAEEAEHGTE LTVLRSLSEL TDVSVRPIRT VIHTSLPGEL
1351 APLAEVTPDA LGA AVSAAAR LSELPGIGSV ETVLFFSSVT ASLGSREHGA
1401 YAAANAYLDA LAQRAGADAA SPRTVSVGWG IWDLPDDGDV ARGAAGLSRR
1451 QGLPPLEPQL ALGALRAALD GGKGHTLVAD IEWERFAPLF TLARPTRL LD
1501 GIPAAQRVLD ASSES AEASE NASALRRELT ALPVRERTGA LLDLVRKQVA
1551 AVLRYEPGQD VAPEKAFKDL GFDSL VVVEL RNRLRAATGL RLPATLVYDY
1601 PTPRTLAAHL LDRVLPD GGA AELPVA AHL DLEAALTDLP ADDPRRKGLV
1651 RRLQTLLWKQ PDAMGAAGPA DEEEQAAPED LSTASADDMF ALIDREWGTR
1701 *

MonH, probable regulatory protein Length: 981 amino acids

1 VSGVERGVGS AGPVEQGDGL AGLVERAEAL AALRGAFDGS PGTGGSLVVL
 51 SGAVGTGKTA LLRAWADRIG ADADALVLT A TACRAERDLP LGVLEQLVRS
 101 PGLPPASAER ALAWWDEEAS ATPGKTDANG TSANGTDANG TGAGQTGAGQ
 151 AGVGQTGVGG EPVLAASALR GLCEVLRDLL AERPVVVAVD DAHHADAASL
 201 QCLLSVVRRL RSARLHVLF T EYAHQKAQNA LLSSEFLHEP ALRRIRLEPL
 251 SKAGVEALLA RHLDERTAQD LTPVVHGMSA GHPLLVRALA EDHRAAGGAG
 301 EAYGRAVLSF LYRHETPVTQ VARAIAALGA HAGPGQVGRL LDVDAASVER
 351 AVRQLTVAEV LHEGRLCHPA FAAAVLDGMP PEERRALHGR VADLLHEEGA
 401 PATEVAAHLV AADRSDAPWA VPFVQEAAQL ALDEDQVETG VDYLRAAHQR
 451 CRGAAQRAAV VGALADAEWR LDPKAVLRHL PDPAAMAPQT DPAALAPHTD
 501 PAPTAAPTAA PTPTPIPTTP PLPTHLLWHG RVEEGLDAIG TLTGPGPNPA
 551 GAPPMNPADL DTPWLWGAYL YPGHVKERLG SGALSPQRST PPAVTPELQG
 601 AGTLMNDLLH GGERDATEAA ERALNRYRLG PRTIAVQTAA LAALTYRDRP
 651 HRAAAWCDGL VAQADERNSP TWRALFTAWR ALLHLRQGDP AAAEQRAETA
 701 LALLGSKGWG AAIGLPLAAA VQAKAALGDV DGAAALLERP VPQAVFQTRT
 751 GLHYLAARGR YHLATGCHYA ALCDFYACGT RMSSWGVDLP ALEPWRLGAA
 801 EAYLALGEG LARQLVDGQL PLPTPDDGRT WGMTLRLRAA TSPAPARAEL
 851 LDEAVAVLRE SGDTFELARA VADQAVAVRE GGEAERARLL ARKAELLARR
 901 WGSAPAPATV PEPPERPGPA TPDAELTS AE RRVAELAAEG FTNREISRKL
 951 CVTVSTVEQH LTRIYRKLDV RRLDLQAALG *

MonCI, flavin-dependent epoxidase Length: 496 amino acids

1 VTTTRPAHAV VLGASMAGTL AAHVLA RHVD AVTVVERDAL PEEPQHRKGV
 51 PQARHAHLLW SNGARLIEEM LPGTTDRLLA AGARRLGFPE DLVTLTGQGW
 101 QHRFPATQFA LVASRPLLDL TVRQQALGAD NITVRQRTEA VELTGSGGGS

151 GGRVTGVVVR DLDSGRQEQL EADLVIDATG RGSRLKQWLA ALGVPAAEED
 201 VVDAGVAYAT RLFKAPPGAT THFPAVNIAA DDRVREPGRF GVVYPIEGGR
 251 WLATLSCTRG AQLPTHEDEF IPFAENLNHP ILADLLRDAE PLTPVFGSRS
 301 GANRRLYPER LEQWPDGLLV IGDSTAFNP IYGHGMSSAA RCATTIDREF
 351 ERSVQEGTGS ARAGTRALQK AIGAAVDDPW ILAATKDIDY VNCRVSATDP
 401 RLIGVDTEQR LRFAEAITAA SIRSPKASEI VTDVMSLNAP QAELGSNRFL
 451 MAMRADERLP ELTAPPFLPE ELAVVGLDAA TISPTPTPTP TAAVRS*

MonBII, carbon-carbon double bond isomerase Length: 141 amino acids

1 MPDEAARKQM AVDYAERINA GDIEGVLDLF TDDIVFEDPV GRPPMVGKDD
 51 LRRHLELAVS CGTHEVPDPP MTSMDDRFVV TPTTVTVQRP RPMTFRIVGI
 101 VELDEHGLGR RVQAFWGVTD VTMDDPAGPA DTTHPEGIRA *

MonBI, carbon-carbon double bond isomerase Length: 144 amino acids

1 MNEFARKKRA LEHSRRINAG DLDAIIDLYA PDAVLEDPVG LPPVTGHDAL
 51 RAHYEPLLAH HLREEAAEPV AGQDATHALI QISSVMDYLP VGPLYAERGW
 101 LKAPDAPGTA RIHRTAMLV I RMDASGLIRH LKSYWGTS DL TVLG*

MonAVIII, polyketide synthase multienzyme MONS 8, housing extension modules 11 and 12 Length: 3754 amino acids

1 MSNEEKLLDH LKWVTAELRQ ARQRLHDKES TEPVAIVGMA CRYPGGARS
 51 EDLWELVRDG GDAVAGFPDD RGWDLES LYH PDPEHPATSY VRDGAFLYDA
 101 GHFDAEFFGI SPREATAMDP QQRLLLETAW EAIEHAGMNP HALKGS DTGV
 151 FTGVS AH DY L TLISQTASDV EGYIGTGNLG SVVSGRISYT VGLEGP AVTV
 201 DTACSSSLVA IHLASQALRQ GECSLALAGG STVMATPGSF TEFSRQRGLA
 251 PDGRCKPFAA AADGTGWGEG AGVVALELLS EARRRGHKVL AVIRGSATNQ
 301 DGTSNGLAAP NGPSQERVIR AALANARLSA EDIDAVEAHG TGTTLGDP IE

351 AQALIATYGO GRPEDRPLWL GSVKSNIGHT QAAAGVAGVI KVMAMRNGL
401 LPTSLHIDAP SPHVQWEQGS VRLLEPVDW PAERTRRAGI SAFGISGTNA
451 HLILEEAPPE EDAPGPVAAE PGGVVPWVVS GRTPDALREQ ARRLGEFAAG
501 LADASVSEVG WSLATTRALF DQRAVVVGRD LAQAGASLEA LAAGEASADV
551 VAGVAGDVGP GPVLVFPQGQ SQWVGMGQAL LDESPVFAAR IAECEQALSA
601 HVDWSLSDVL RGDGSELSRV EVVQPVWAV MVSLAAVWAD YGITPAAVIG
651 HSQGEMAAAC VAGALSLEDA ARIVAVRSDA LRQLQGHGDM ASLSTGAEQA
701 AELIGDRPGV VVAAVNGPSS TVISGPPEHV AAVVADAEAQ GLRARVIDVR
751 YASHGPQIDQ LHDLLTDRLA DIQPTTTDVA FYSTVTAERL DDTTALDTAY
801 WVTNLRQPVR FADTIEALLA DGYRLFIEAS PHPVLNLGIQ ETIEQQAGAA
851 GTAVTIPTLR RDHGDTTQLT RAAAHAFATAG APVDWRRWFP ADPTPRTVDL
901 PTYAFQHKHY WVEPPAAVAA VGGGHDPVEA RVWQAIEDLD IDALAGSLEI
951 EGQAESVGAL ESALPVLSAW RRRHREQSTV DSWRYQVTWK HLPDVPAPEL
1001 SGAWLLLPA AHADHPAVLA TAQTLTAHGG EVRRHVVDAR AMERTELAQE
1051 LRVLMDGAAF AGVVNLLALD EEPHPEHSAV PAGLAATTAL VQALADNGAD
1101 IAVRTLQGA VSTSAGDAL HPVQAQVWGL GRVAALEYPR LWGGLVDLPA
1151 RIDHQTLARL AAALVPQDED QISIRPSGVH ARRLAHAPAN TVGSGLGWRP
1201 DGTTLITGGT GGIGAVLARW LARAGAPHLL LTSRRGPDAP GAQELAAELT
1251 ELGAAVTVTA CDVGDREQVR RLIDDVPAEH PLTAVIHAAG VPNYIGLGDV
1301 SGAEDEVLR PKALAAHHLH ELTREPLSA FVMFSSGAGV WSGSQQAYG
1351 AANHFLDALA EHRRAEGLPA TSIWGPWAE AGMAADQAAL TFFSRFGLHP
1401 LSPELCVKAL QQALDAGETT LTVANFDWAQ FTSTFTAQRP SPLADLPEN
1451 RRASAPAAQQ EDATEASSLQ QELTEAKPAQ QRQLLLQHVR SQAAATLGHS
1501 DVDAVPATKP FQELGFDSL AVELRNRLNK STGLTLPTTV VFDHPTPDAL

1551 TDVLRaelSG DAAASADpVR AAGASrgaAD DEPIaIVGMA CRYPGDVRSA
1601 EELWDLVAAG KDAMGAfPDD RGWDLEtLYD PDpESRGtSY VREGGfLYDA
1651 GDFDAGffGI SPREAVAMDP QQrLLLEtAW EAIERAGLDR ETLKGSDAGV
1701 FTGLTIFDYL ALVGEQpTEV EGYIGtGNLG CVASGRvSYV LGLEGPAMtI
1751 DTGCSSSLVA IHQAAHALRQ GECSLALAGG ATVMATPGsF VEFSLQrGLA
1801 KDGRCKPFAA AADGTGWAEG VGLVVLERLS EARRNGHNVL AVIRGSAINQ
1851 DGTSNGLTAP NGQAQQRVIR QALANARLSA EDVDAVEAHG TGTMLGDPIE
1901 ASALVATYgK ERPADRPLWL GSIKSNIGHA QASAGVAGVI KMVMALRNEQ
1951 LPASLHIDAP TPHVDWDGSG VRLlSEPvSW PRGERPRRAG VSAFGISGTN
2001 AHLILEQAPD APEPVTAPAE DAAAPAGVVP WVVSARGEeA LRAQARLLAD
2051 RATADPRLAS PLDVGWsLVK TRSVfENRAV VVGKDRQTLl AGLRSLAAGE
2101 PSPDVVEGAV QGASGAGPVL VFPGQGSQWV GMGAQLlDES PVFAARIAEC
2151 ERALSAHVDW SLSAVLRGDG SELSRVEvVQ PVLWAVMVSL ASVWADYGIT
2201 PAAVIGHsQG EMAAACVAGA LSLEDAARIV AVRSDALRQL MGQGDMAStG
2251 AGSEQVAELI GDRPGVCVAA VNGPSStVIS GPPEHVAAvV ADAEARGLRA
2301 RVIDVGYASH GPQIDQLHDL LTERLADIRP TTTDVAfYST VTAERLDDtT
2351 TLDTDYWVTN LRQPVRfADT IEALLADGYR LFIEASpHPV LNLGMEETIE
2401 RADMPATVVP TLRRDHGDAA QlTRAAaQAF GAGAEVDWTG WFPaVPLPRV
2451 VDLPTYAFQR ERfWLEGRRG LAGDPAGLGL ASAGHPLLGA AVELADGGSH
2501 LLTGRISPRD QAWLAeHRVM DTVLLPGsAF VELALQAaVR AGCAELAElt
2551 LHTPLAFGDE GAGAVDVQvV VGSVAEDGRR PVTVHSRPTG EGEEAVWtRH
2601 AAGVVAPPGP DAGDASfGGT WPPPGATPVG EQDPYGELAS YGYDFGPGsQ
2651 GLVSAWRLGD DLfAEVALPE AESGRADRYQ VHPVLLDATL HALILDAVtS
2701 SADTDQVLLP FSWSGLRVHA PGAEKLRVRI ARTAPDQLAL TAVDGGGGGGE

2751 PVLTL[•]ESL[•]TV RPVAAHQIAG ARAADRDALF RLVWMEVAAR AEETGGGAPR
 2801 AAVLAPVESG PMGGTSAGAL ADALSDALAA GPVWDTFGAL RDGVAAGGEA
 2851 PDVVLAVCAA PGAGAGAVAD ADGRGGDPAG YARLATVSLL SLLKEWVDDP
 2901 AFAATRLVVV TRGAVAARPG ETAGDLAGAS LWGLVRSQA ENPGRLTLLD
 2951 VDGLESSPAT LTGVLASGEP ELALRDGRAY VPRLVRDDAS VRLVPPVGS
 3001 TWRLARCQEA GGGQQLSLVD APEAGRALEP HEVRVAVRAA APGPLTAGQV
 3051 EGAGVVTEVG GEVGSVAVGD RVMGLFDAVG PVAVTDAALL MPVPAGWSWA
 3101 QAAGSLGAYV SAYHVLADV APRGGETLLV GEETGSVGRA VLRLALAGRW
 3151 RVEAVDGAST ADDSGAERAA DVTLRHEGAL VVHRAGGRPD EGQAVVPPEP
 3201 GRVREILAE TELTELA[•]EIT ESAEPGLPAE RGDSRALTPL DITVWDIRQA
 3251 PAAMAAPPSA GTTVFSLPPA FDPEGTVLVT GGTGALGSLT ARHLVERYGA
 3301 RHLLLSRRG ADAPGALELA ADLSALGARV TFAACDPGDR DEAAALLAAV
 3351 PSDHPLTAVF HCAGTVNDAV VQNLTAEQVE EVMRVKADAA WHLHELTRDA
 3401 DLSAFVLYSS VAGLLGGPGQ GSYTAANAFL DALARHRHDG GAAATSLAWG
 3451 YWELASGMSG RLTDADRARH ARAGVVGLGA DEGLALLDAA WAGGLPLYAP
 3501 VRLDLARMRR QAQSHPAPAL LRDLVRGGSK SGGGAVSAGA AALLKSLGAM
 3551 SDPEREEALL DLVCTHIAAV LGYDAATPVN ATQGLRELGF DSLTAVELRN
 601 RLSAATGLKL PATFVFDHPN PAELAAQLRQ ELAPRAADPL ADVLAEFERI
 3651 EDSLLSVSSK DGSARAELAG RLRATLARLD APQDTAGEVA VATRTRIQDA
 3701 SADEIFAFID RDLGRDGASG QGNGQPTGQG NGHNGNGNG NGNGHGQAVE
 3751 GQR*

MonAVII, polyketide synthase multienzyme MONS 7, housing extension module 10 Length: 1642 amino acids

1 MAHTEEKLL EYLKRV[•]TADLR QTERRLQDVE SAGHEPVAVI GMACRLPGGV
 51 RSPEEFWELV STGGDAVAPL PGNRNWDLDS LYDPDPESTG TSYVREGGFV

101 YDAGDFDPTF FGIGPTEAAA MAPQORLAL E TAW EAIERAG IDPLSLRSSD
151 TSTFIGCDGL DYALGASEVP EGTAGYFTIG NSGSVTSGRV AYTLGLEGPA
201 VTVDTACSSS LVSLHLATQA LRTQECSLAL AGGTYVMSSP APLIGFSELR
251 GLAPDGRCKP FSASSDGMGM AEGTGVVLE RLSDARRKGH KVLAVIRGSA
301 INQDGASNGL TAPNGPAQER VIRAA LANAR LAPEDIDAVE AHGTGTTLGD
351 PIEAGALISA YGRERPEDRP LWVGAVKSNI GHTQIAAGVA GVIKMLALR
401 HDLLPAILHV DAPSPHVEWD GSGLRLLTDP VKWPRGERPR RAGVSSF GFS
451 GTNAHLILEE APPEEEDVPG SVAEEP GG VV PWVVS GRTPD ALRAQARRLG
501 EFAAGPADAS AADV GWSLTT TRSVFEHRAV VVGRDRDALT AGLGALAAGE
551 ASAGVVAGVA GDVGPGPVLV FPGQGSQWVG MGAQLLDESP VFAARIAECE
601 RALSAYVDWS LSAVLRGDGS ELSRVEVVQP VLWAVMVSLA AVWADYG VTP
651 AAVIGHSQGE MAAACVAGAL SLEDAARIVA VRSDALRRLQ GHGDMASLST
701 GAEQAAELIG DRPGVVAAV NGPSSTVISG PPEHVA AVVA DAEARGLRAR
751 VIDVGYASHG PQIDQLHDLL TERLADIRPA NTDVAFYSTV TAERLTDTTA
801 LDTDYWVTNL RQPVRFADTI EALLADGYRL FIEASAH PVL GLGMEETIEQ
851 ADIPATVVPT LRRDHGDTTQ LTRAAAH AFT AGAPVDWRRW FPADPTPRTV
901 DLPTYAFQHQ HYWLERSASA SGA VS GEQSA AEAQLWHAVE ELDLGLLAET
951 LGSEEGSEEA VRALEPALPV LKGWRRRHQD QATIDSWRYR VTWKQRS DGP
1001 APELGGDWLL FVPADKAEHP AVRATAEALS EHGA AAVRLH PVETGRAGRQ
1051 ELAAVDTAGL AGIVNLLALD EEPHPEHPAV PAGLAATTAL LQALGDNGTT
1101 APLHTVTQGA VSTGATDPLT HPLQAHVWGL GRVA ALEHPR LWAGLVDLPA
1151 RIDRHTLPRL AAALLPQDDE DQTAVRPTGI HHRRLTHAVG SIQNPVHSEA
1201 TWRPRGTTLI TGGTGGIGAV LARWLARQGA PRLHLTSRRG PDAPGARELA
1251 AELDGLGTAV TITACDVSDP RQLSGLIDDM PAEHPLTAVI HAAGMTDLTA

1301 IGDLTARLG EVLGSKSDAA WNLHELTRDL DLSAFVMFSS GAGVWGSGQQ
1351 GAYGAANHFL DALAEHRRAQ GLPATSIWGW PWAEAGMSAD PESLTYFKRF
1401 GLLPIAPDLC VKALHQAVDA GDATLTVANF DWAKFTPTFT AQRPSFLLDD
1451 LPENQREAEQ TGTAETSASF REELAKTPAS QRLGFLVQQV RTYAAATLGR
1501 TVEDIPAAKP FQELGFDSL TAVQLRNQLNT TTGLSLPATV IFDHPTPEAL
1551 ATHLRGQLGD GAEVAGEGDV LAALDKWDTA FGAAEVDEAA RRRIVGRLQV
1601 LVSKWSPAQD GPEGTDSAHA DLEAASADDI FDLISSEFGK S*

MonD, cytochrome P450 hydroxylase Length: 431 amino acids

1 VGLTVGPDNA KRGIVPITDS KPAATFPDLV DPSFWARPHA ERVALFEEMR
51 GLPRPAFIRQ NMPGVPWTFG YHALVKYADI VEVSRRPQDF SSNGATTIIG
101 LPPELDEYYG SMINMDNPEH SRLRRIVSRS FGRNMIPEFE AVATRTARRI
151 IDELIARGPG DFIRPVAAEM PIAVLSDMMG IPAEDHDFLF DRSNTIVGPL
201 DPDYVPDRAD SERAVIEASR ELGDYIAGLR AERLAAPGND LITKLVQVQA
251 DGEQLTRQEL VSFFILLVIA GMETTRNAIS HALVLLTEHP EQKQLLLSDF
301 DTHAPNAVEE ILRVSTPINW MRRVATRD CD MNGHRFRRGD RIFLFYWSGN
351 RDESVPDPY RFDIRGTNA HVTFGAVGPH VCLGAHLARM EITVLYRELL
401 AALPQIHAVG QPRRLDSSFI EGIKHLHCAF *

MonRI, probable activator protein Length: 268 amino acids

1 VRYEMLGPLR IKDGNDYATI NAQKVEIVLT VLLIRADRVV SLEQLMREIW
51 GEDLPRRATA GLHVIISQLR KFLKVPGSAG NPVETRAPGY VLHKRDDDQI
101 DAQIFPELVD VGRSLLREKR FDEAASCFCGQ ALALWRGPIL GQGGNGPGTN
151 GPIIDGFSTW LTEIRLECQE MLVEQCQLQG RHREAVGMLY ALTAENPMCE
201 AFYRQLMLAL YRSERQADAL KVIQSVRCTL NDELGLEPGR PLQELQRAIL
251 AGDMHLMSP PLALSGR*

MonAX, thioesterase Length: 278 amino acids

1 LSAFLAKGKI LSAFPPPDMS DPWIRRRFRPR PEAVVRLVCF PHAGGSASY
51 HPLAQSP TLP TDSEVLAVQY PGRQDRRRER LLDDIGELAD LITDALGPFD
101 DRPLAFFGHS MGAVLAYEVA QRLRERTGKQ PCRLFVSGRR APSRFRRGTV
151 HLLDDTELA ELRRAGGTDP RFLDDEELLA EIIPVVRNDY RAVELYRWNP
201 SPPLSCPITA LVGDRDPQAP LDEVEAWQQH TEGPFDLKVF AGGHFYLNTH
251 QQGVTEVISK ALADSAQQRA TARGNAR*

ORF29, a homologue of CapK involved in cell wall biosynthesis Length: 428 amino acids

1 LADLVAHARS ASPYYRELYH GLPERIEDPT LLPVTDKKQL MDHFDDWPTD
51 RDITFEKVRA FTDDPELIGR RFLGRYLVAT TSGTSGRRGL FVLDDRYMNV
101 SSAVSSRVLA SWLGPLGIAR AVVHGG RFAQ LVATEGHYVG FAGYSRLRQD
151 GEARSKLVRA FSVHEPMSRL VAE LNEYRPA FVIGYASTIM LFTAEQEAGR
201 LHIDPVLVEP AGETMTESDT DRIAAAFGAK VRTMYSATEC TYLSHGCAEG
251 WYHVND DWAV LEPVDADHRP TPPGEFSHTT LISNLANRVQ PFLRYDLGDS
301 VMLRPDPCPC GTPSPAIRVQ GRSGDILTFP SGRGDDVSLA PLAFSSLFDR
351 MPGVELFQIE QTAPSTLRVR VVQAPGADAD HVWQRAHDGL THLLADNKLD
401 NVTVERGEEP PRQASGGKYR TIIPLAA*

LipB, lipase B Length: 338 amino acids

1 VKVPVEVTVR LSSWLGLVA AVLAATV LPA SAASAADVSS PPLEIPAAEL
51 AKALHCGTEL GDLRDAGDKP TVLFVPGTGL KGEENYAWNY MAELKKKGYQ
101 SCWVDSPGRG LRDMQESVEY VVYATRAIQE ATGRKVDLVG HSQGGLLTAW
151 ALRFWPDLPG KVDDMVT LGS PFQGTRLASP CRPIAEVAGC PASVLQFARD
201 SNWSKALGAD GTPMPAGPSY TTIYSYADES VVADGEAPSL PGAHRIGVQD

251 ICPGRPWP TH IAMVVDQVS Y DLVADAIEHP GPADTSRIDR AHCAKPMPL
301 NSQEAVDALP GLLNFPIELL IHSQPWVDEE PPLRPYAR*

ORF31, putative ion pump Length: 309 amino acids

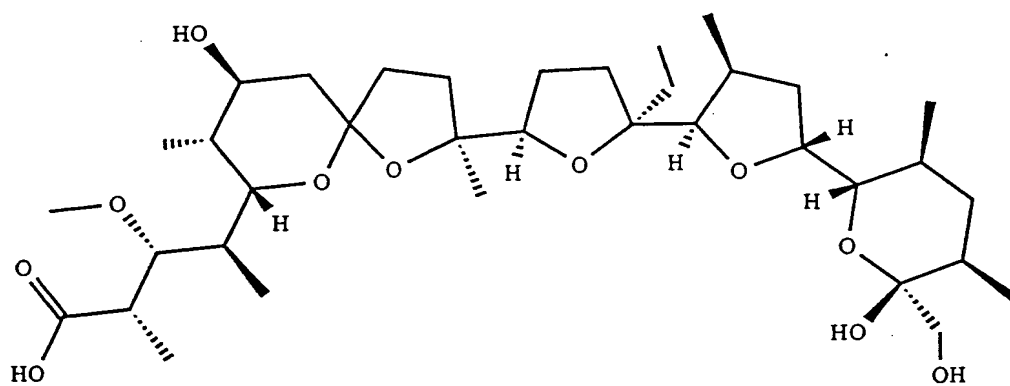
1 MGHDHGPSAG AAGGTLSGTY RKRLLTIGI SGSITVIQVV GALLSGSLAL
51 LADAAHSLTD AVGVSLALGA ITLAQRAPT RRTFGFCRVE IFSAVLNALL
101 LVVIFAWVLW SAIGRFSEPV EVKGGLMFVV ALGGLAANLV GLWLLRDAKE
151 KSLNLRGAYL EVLGDALGSV AVIVGGLVIL LTGWQAADPI ASIVIGLLIV
201 PRAYGLLRDS LHVLLLEATPQ DVDLGEVRRH LLEERG VVAV HDLHGWTVTS
251 GMPVLT AHVV VTEEALASGY GELLGRLQRC VGGHFDVAHS TIQLEPEGHV
301 EEDGALHT*

ORF32, hypothetical membrane protein Length: 364 amino acids

1 MTRALTLHDW IVAGIAVVAG VVAGLLLRAL LRWLGERASK TRWSGDDVIV
51 DALRTLVP CA AITAGLAAAA GALPLTPRTG RNVTMTLTAL LILAATLTAA
101 RIVTGLVKAV AQSRSGVAGS ATIFVNITRV VVLAMGFLIV LQTLGISIAP
151 LLTALGVGGL AVALALQDTL ANLFAGVHIL AAKTVQPGDY IQLSSGEEGY
201 VVDINWRNTT VRQLSNNLVI IPNAKLAGTN MTNYSRPEQE LSIMVQVGVS
251 YDSDLEQVEK VTTEVVDEVM AEITGAVPDH EAAIRFHTFG DSRISFTVIL
301 GVGEFSDQYR IKHEFIKRLH QRYRAEGIRV PAPVRTVRVQ QGELPPPLGI
351 PHQRTSTQA RLH*

**AmtA, glycine amidinotransferase (partial coding sequence)
Length: 131 amino acids**

1 MSPVNSHNEW DPLEEIIVGR LEGATIPSSH PVVACNIPTW AARLQGLAAG
51 FEYPQRLIEP AQQELDQFIA LLQSLDVTVR RPAAVDHKHR FGTPDWQSRG
101 FCNSCPRDSM LVVGDEIIET PMAWPCRCFE T



monensin A : R = ethyl
monensin B : R = methyl

Fig 1

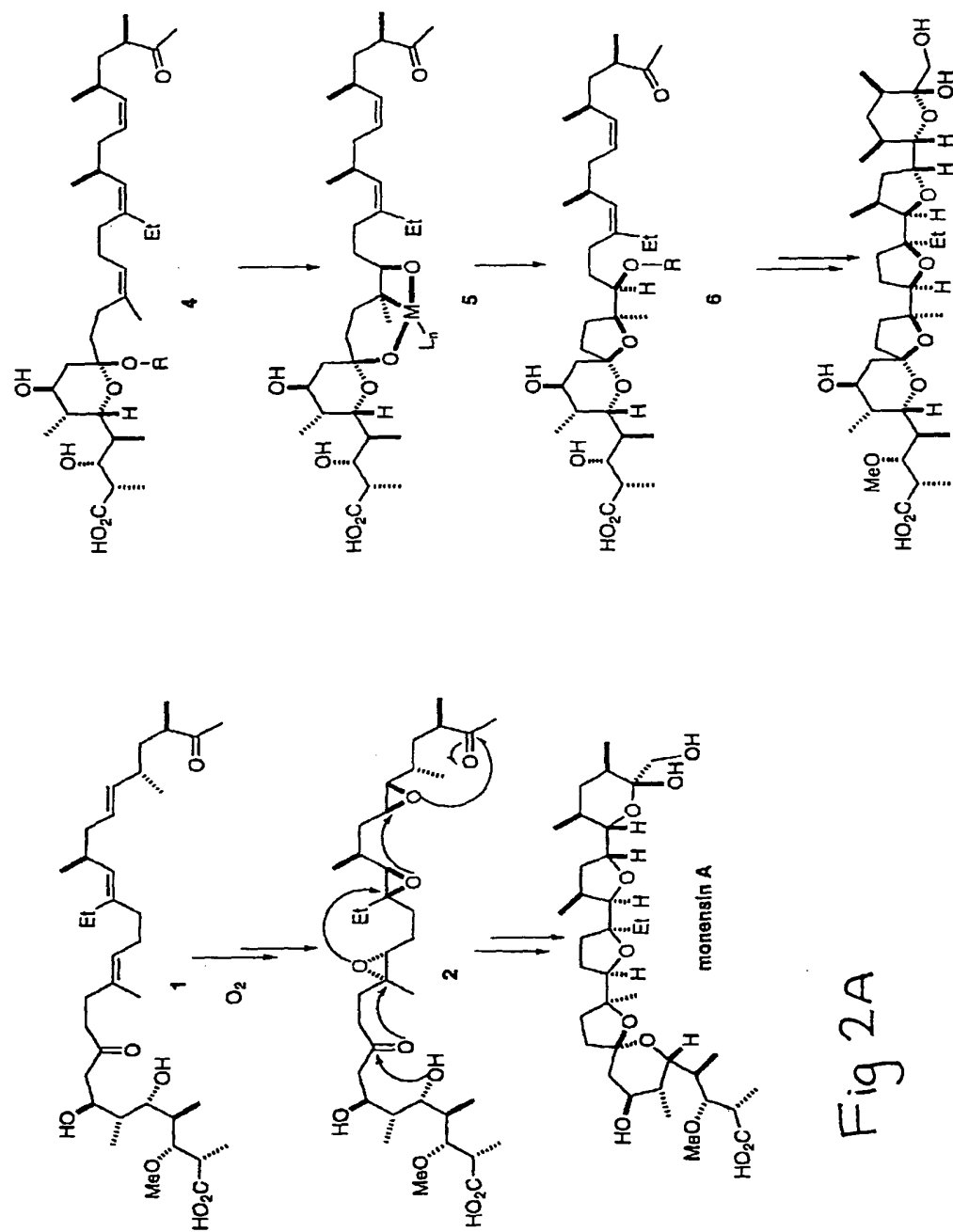


Fig 2B

Figure 2. Proposed mechanisms for monensin biosynthesis.





Organisation of the Monensin Biosynthetic Gene Cluster

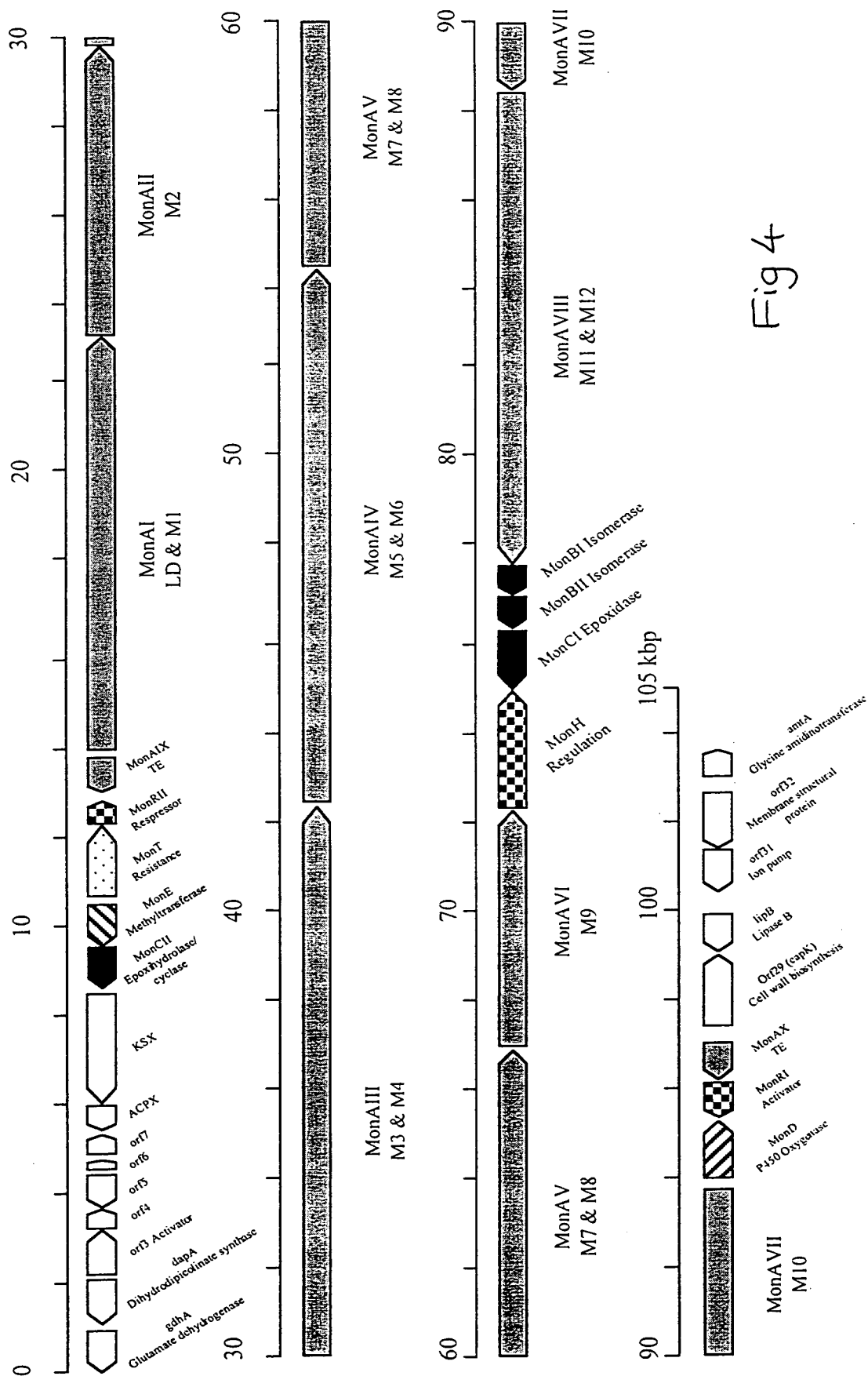


Fig 4

PCT/GB Not given

30/5/00

Mewburn Ellis.